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Tests of Chain Links

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# TESTS OF CHAIN LINKS

BY

Robert Mills Evans

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THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

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IN THE
COLLEGE OF ENGINEERING
OF THE
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June 1, 1906

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ROBERT MILLS EVANS

ENTITLED TESTS OF CHAIN LINKS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge.

HEAD OF DEPARTMENT OF Mechanical Engineering

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References. ——

An Investigation of the Stresses in Links with Elliptical & Oval Centre-Lines. by. T. A. Goodenough.

Thesis for Degree of M. E. University of Illinois.
Which contains derivation of formulae for various forms of links, together with a review of Bachs previous work on curved pieces under stress.

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# Tests of Chain-Links

I

## I Object

The object of this thesis is a practical investigation of certain mathematical formulae for stresses in chain-links.

These were deduced by Prof. G. A. Goodenough using Bachs curved beam theory as a basis.

The tests were made to prove the correctness of this analysis, and hence the reliability of loading formulae based on this same analysis.

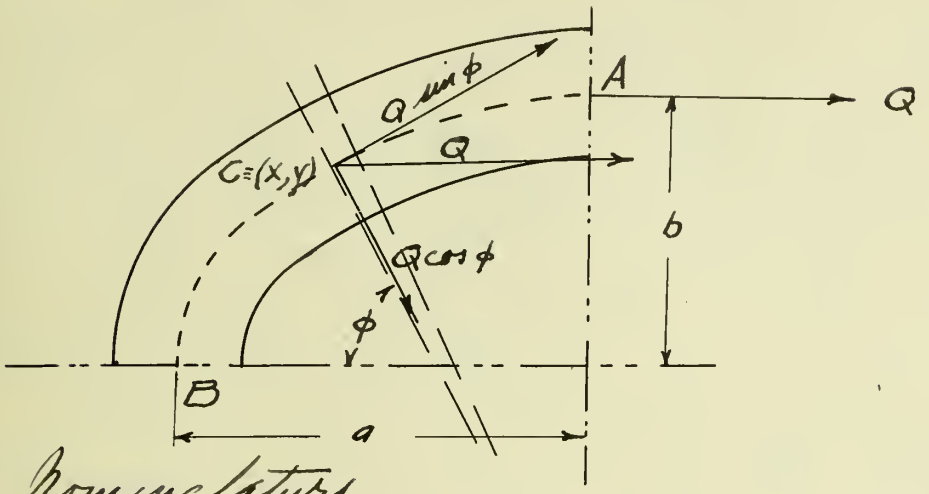
## II Method.

The method of procedure was as follows. Chain links of various forms were loaded under normal conditions and deformations for various loads accurately measured.

Then deformations which should have been produced by these loads according to Bachs' theory were calculated and plotted on the same sheet with actual results

The accuracy of the theory was then judged by a comparison of these results.

## III Review of G. A. Goodenoughs Work.




Nomenclature

$f$ = Area of section of link iron.

$E$ = Modulus of elasticity

$x$ = Function similar to moment of inertia

$Q$ = Half of load on link.

$M_b$ = Total bending moment at any section

$M$ = Bending moment at section A.

$P$ = Normal force at any section.

$r$ = Radius of curvature

$\Delta b$ = Deformations of minor axis of link.

$\Delta a$ = Deformations of major axis of link.

$\phi$ - Angle between any section and major axis.

1. From Bach's work comes the following fundamental relations. That the elongation of an infinitesimal segment of length $ds = s\,ds$ and that $s\,ds = \epsilon_0\,ds$ second the change in angularity of planes bounding an infinitesimal segment, where the original angle is $d\phi = s\,d\phi$ and ~~that~~ $s\,d\phi = w\,d\phi$

From which as a basis, considering the form of the piece comes the following.

$$w - \epsilon_0 = \frac{M_b}{EfrK}$$

and
$$\epsilon_0 = \frac{P}{Ef} + K(w - \epsilon_0) = \frac{1}{Ef}\left(P + \frac{M_b}{r}\right)$$

$$w = \epsilon_0 + \frac{M_b}{EfKr} = \frac{1}{Ef}\left(P + \frac{M_b}{r} + \frac{M_b}{Kr}\right)$$

in which $K$ for circular section equals.

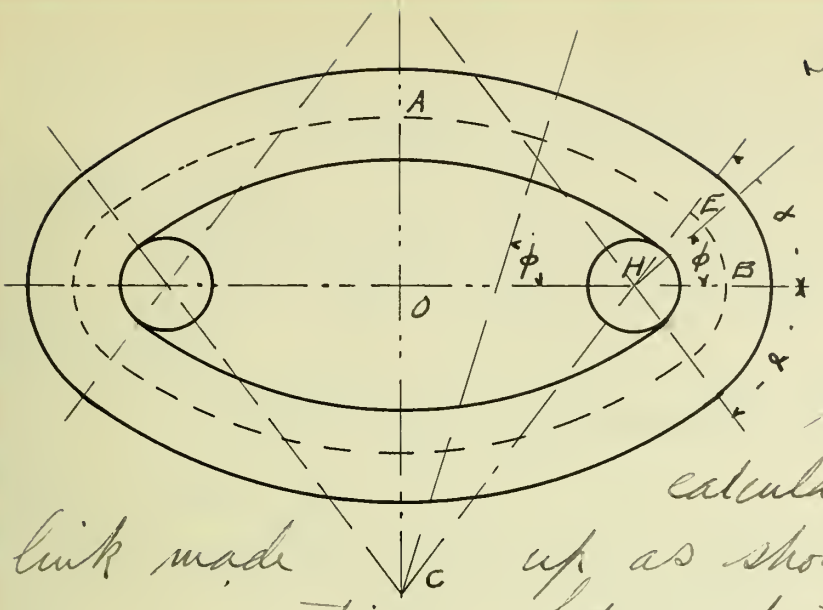
$$K = \frac{1}{4}\left(\frac{c}{r}\right)^2 + \frac{1}{8}\left(\frac{c}{r}\right)^4 + \frac{5}{64}\left(\frac{c}{r}\right)^6$$

and
$$\frac{1}{K} = 4\left(\frac{r}{c}\right)^2 - 2 - \frac{1}{4}\left(\frac{c}{r}\right)^2$$

in which $c$ is radius of circular section.

2. Determination of Stresses.

Since the links as shown by sketches do not even closely approximate the ellipse in form, their center lines are approximated by four circular arcs, same being the basis of stress formulae, deduction of which follows.




This four arc approximation gives two constant values of function $\kappa$ thus simplifying the calculations. Take link made up as shown with H & C as arc centres. Let $\alpha$ denote angle EHB, $r$ the radius CE = CA, semi-axis OA by $b$ and semi-axis OD by $a$. Then from geometry of the figure the following relations are obtained.

$$\tan\alpha = \frac{r-b}{a-d}\ ;\quad \sin\alpha = \frac{r-b}{r-d}\ ;\quad \cos\alpha = \frac{a-d}{r-d}\ ;$$

$$r = \frac{a^2+b^2-2ad}{2(b-d)}.$$

For $\phi$ from 0 to $\alpha$ $\qquad P = Q\sin\phi$

$$M_b = M + Q(b - d\sin\phi)$$

General expression for $w$ is

$$w = \frac{1}{Ef}\left(P + \frac{M_b}{r} + \frac{M_b}{\kappa r}\right)$$

For $0 < \phi < \alpha$ $\quad r = d$ and

$$w_1 = \frac{1}{Ef}\left(Q\sin\phi + \frac{M_b}{d} + \frac{M_b}{\kappa_1 d}\right)$$

For $\alpha < \phi < \frac{\pi}{2}$ $\qquad w_2 = \frac{1}{Ef}\left(Q\sin\phi + \frac{M_b}{r} + \frac{M_b}{\kappa_2 r}\right)$

Inserting the proper values of $M_b$

$$Ef w_1 = \frac{M+Qb}{d}\left(1+\frac{1}{\kappa_1}\right) - \frac{Q}{\kappa_2}\sin\phi$$

$$Ef w_2 = \left(\frac{M}{r}+Q\right)\left(1+\frac{1}{\kappa_2}\right) - \frac{Q}{\kappa_2}\sin\phi$$

since sections A x B remain at right angles.

$$\int_0^{\alpha} \omega_1 \, d\phi + \int_{\alpha}^{\frac{\pi}{2}} \omega_2 \, d\phi = 0 \; ;$$

substituting

$$0 = \frac{M + Qd}{d}\left(1 + \frac{1}{\mu_1}\right)\int_0^{\alpha} d\phi - \frac{Q}{\mu_1}\int_0^{\alpha} \sin\phi \, d\phi + \left(\frac{M}{r} + Q\right)\left(1 + \frac{1}{\mu_2}\right)\int_{\alpha}^{\frac{\pi}{2}} d\phi - \frac{Q}{\mu_2}\int_{\alpha}^{\frac{\pi}{2}} \sin\phi \, d\phi \; ;$$

integrating

$$0 = \frac{M + Qb}{d}\left(1 + \frac{1}{\mu_1}\right)\alpha - \frac{Q}{\mu_1}(1 - \cos\alpha) + \left(\frac{M}{r} + Q\right)\left(1 + \frac{1}{\mu_2}\right)\left(\frac{\pi}{2} - \alpha\right) - \frac{Q}{\mu_2}\cos\alpha .$$

Solving for $M_1$

$$M = Qd\left[\frac{\frac{1}{\mu_1}(1 - \cos\alpha) + \frac{1}{\mu_2}\cos\alpha - \frac{b}{d}\alpha\left(1 + \frac{1}{\mu_1}\right) - \left(\frac{\pi}{2} - \alpha\right)\left(1 + \frac{1}{\mu_2}\right)}{\alpha\left(1 + \frac{1}{\mu_1}\right) + \frac{d}{r}\left(\frac{\pi}{2} - \alpha\right)\left(1 + \frac{1}{\mu_2}\right)}\right]$$

Knowing $M$, $M_b$ for any section can easily be obtained. Then the stress $\sigma = \frac{P}{f} + \frac{M_b}{fr}\left(1 + \frac{1}{\mu}\left[\frac{\eta}{r + \eta}\right]\right)$

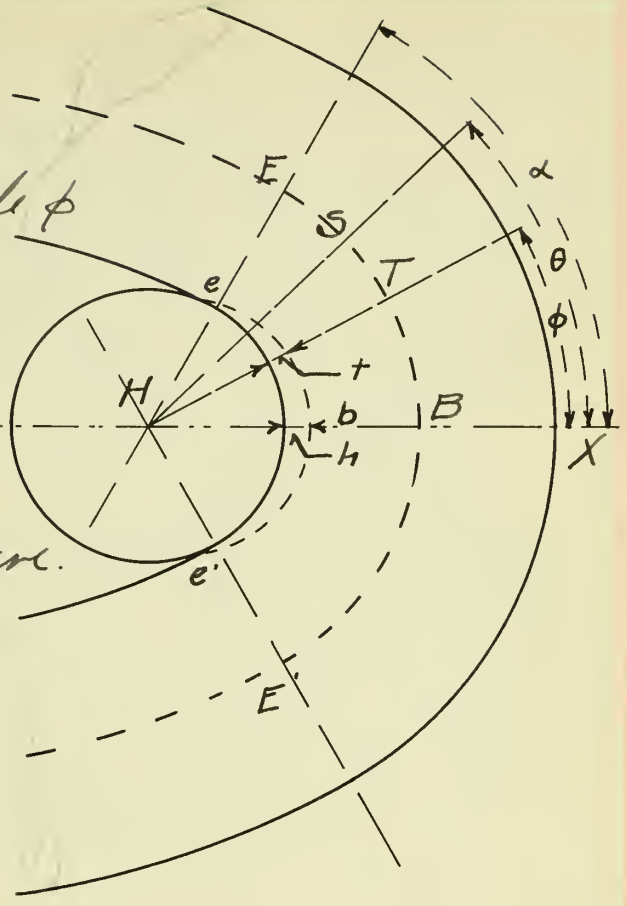
The concentrated load assumption makes the analytical work easy, but can hardly be justified. In reality links have considerable surface in contact, especially after some use, and the pressure must be distributed in some way.

The law of "Equal Wear" seems a reasonable assumption for this case, for though the portions of links in contact are curved the action is comparable to a journal.

Let arc of contact be denoted by $2\alpha$, As the link wears, the surface of contact will become that shown by dotted arc $e\,e'$; which is approximately a circular arc with the radius of a section of the link. Evidently the wear is greatest at $b$ and

least at e and e'.

Let t denote the depth of wear at a section making the angle $\phi$ with the axis HX, and h the depth at section B. Since the center of the arc ee' is at a distance h to the right of the center O, we have.




$$r^2 = h^2 + (r+t)^2 - 2h(r+t)\cos\phi.$$

$$2rt + t^2 = h[2(r+t)\cos\phi - h]$$

$$\frac{t}{h} = \frac{2(r+t)\cos\phi}{2r+t} - \frac{h}{2r+t}$$

Limit $\frac{t}{h} = \cos\phi$, $h = 0$

That is, the wear at any point of the circumference in contact is proportional to cosine of the angle which the section makes with major axis of the link. Now wear is proportional to work of friction, which is proportional to normal pressure, hence it is probable that the pressure between links is distributed in such a manner, that if p denotes intensity of pressure at the axis HB, $p\cos\phi$ will be the intensity at a point where radius makes an angle $\phi$ with HB.

With the pressure thus distributed, the sections of that portion of the link in contact with its neighbor will be subjected to a bending

moment and normal force different from those deduced for the concentrated load.

Let $p$ denote the intensity of pressure at the section at the small end of the link, that is, the one containing the axis HB. Then $p\cos\phi$ will be the intensity at a section making an angle $\phi$ with this axis. The length of an elementary arc of the circumference in contact is $\frac{d}{2}d\phi$, hence the pressure on the elementary arc is $p\cos\phi\frac{d}{2}d\phi$; the horizontal component of which is $\frac{pd}{2}\cos^2\phi\,d\phi$. Sum of these components must balance external force $\Sigma Q$

$$\therefore \frac{pd}{2}\int_{-\alpha}^{+\alpha}\cos^2\phi\,d\phi = \Sigma Q$$

But $$\int_{-\alpha}^{+\alpha}\cos^2\phi\,d\phi = \frac{\phi+\sin\phi\cos\phi}{2}\Big]_{-\alpha}^{+\alpha} = \alpha+\sin\alpha\cos\alpha = k$$

Hence $$\frac{pd}{2}k = \Sigma Q \quad \text{or} \quad p = \frac{2Q}{kd}$$

We have now to find the bending moment at a section T making an angle $\phi$ with OX due to distributed pressure between sections S and T. Take any section as S making the variable angle $\theta$ with OX, the angle $\phi$ being considered for the present as a constant. Pressure on an infinitesimal arc of the circumference is

$$\frac{pd}{2}\cos\theta\,d\theta$$

Component of this force perpendicular to OT is

$$\frac{pd}{2}\cos\theta\sin(\theta-\phi)\,d\theta$$

Moment of this component, whose line of action of course passes through O, about T is

$$d\times\frac{pd}{2}\cos\theta\sin(\theta-\phi)\,d\theta=\frac{pd^2}{2}\cos\theta\sin(\theta-\phi)\,d\theta.$$

Hence

$$\text{Normal force at T}=\frac{pd}{2}\int_{\phi}^{\alpha}\cos\theta\sin(\phi-\theta)\,d\theta$$

$$\text{Moment at T}=\frac{pd^2}{2}\int_{\phi}^{\alpha}\cos\theta\sin(\phi-\theta)\,d\theta$$

These are merely the force and moment due to the distributed pressure between sections S and T.

$$\int_{\phi}^{\alpha}\cos\theta\sin(\theta-\phi)=\cos\phi\int_{\phi}^{\alpha}\sin\theta\cos\theta\,d\theta-\sin\phi\int_{\phi}^{\alpha}\cos^2\theta\,d\theta$$

$$=\frac{\cos\phi}{2}(\sin^2\alpha-\sin^2\phi)-\frac{\sin\phi}{2}(\alpha+\sin\alpha\cos\alpha-\phi-\sin\phi\cos\phi)$$

$$=\frac{1}{2}(\cos\phi\sin^2\alpha-k\sin\phi+\phi\sin\phi)$$

$$\text{Normal force}=\frac{pd}{2}(\sin^2\alpha\cos\phi-k\sin\phi+\phi\sin\phi)$$

$$=\frac{Q}{k}(\sin^2\alpha\cos\phi-k\sin\phi+\phi\sin\phi)$$

$$\text{Moment}=\frac{Qd}{k}(\sin^2\alpha\cos\phi-k\sin\phi+\phi\sin\phi)$$

As has been shown, the normal force at section T due to the force Q at section A is $Q\sin\phi$; adding to this the normal force due to the distributed pressure.

$$P=Q\sin\phi+\frac{Q}{k}(\sin^2\alpha\cos\phi-k\sin\phi+\sin\phi)$$

$$=\frac{Q}{k}(\sin^2\alpha\cos\phi+\phi\sin\phi)$$

The bending moment at the section T due to Q is

$$M + Q(b - d\sin\phi)$$

From this must be subtracted the moment due to the distributed pressure, the two having opposite signs.

Hence $$M_b = M + Qb - Qd\sin\phi - \frac{Qd}{K}(\sin^2\alpha\cos\phi - K\sin\phi + \phi\sin\phi)$$

$$= M + Qb - \frac{Qd}{K}(\sin^2\alpha\cos\phi + \phi\sin\phi)$$

Substituting

$$w_1 = \frac{1}{Ef}\left[\frac{Q}{K}(\sin^2\alpha\cos\phi + \phi\sin\phi) + \frac{1}{d}\left(1+\frac{1}{K_1}\right)\left\{M + Qb - \frac{Qd}{K}(\sin^2\alpha\cos\phi + \phi\sin\phi)\right\}\right]$$

$$Ef\int_0^\alpha w_1\,d\phi = \frac{1}{d}(M+Qb)\left(1+\frac{1}{K_1}\right)\int_0^\alpha d\phi - \frac{Q}{KK_1}\sin^2\alpha\int_0^\alpha\cos\phi\,d\phi - \frac{Q}{KK_1}\int_0^\alpha \phi\sin\phi\,d\phi$$

$$= \frac{\alpha}{d}(M+Qb)\left(1+\frac{1}{K_1}\right) - \frac{Q\sin^3\alpha}{K\,K_1} - \frac{Q\sin\alpha}{K\,K_1} + \frac{Q\alpha\cos\alpha}{K\,K_1}$$

Adding to this the integral $\int_\alpha^{\frac{\pi}{2}} w_2\,d\phi$ we have

$$0 = \frac{\alpha}{d}(M+Qb)\left(1+\frac{1}{K_1}\right) - \frac{Q}{KK_1}(\sin^3\alpha + \sin\alpha - \alpha\cos\alpha) + \left(\frac{M}{r}+Q\right)\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right) - \frac{Q}{K_2}\cos\alpha$$

or

$$M = Qd\left[\frac{\frac{1}{K_1}\left(\frac{2\sin\alpha}{K} - \cos\alpha\right) + \frac{1}{K_2}\cos\alpha - \frac{b}{d}\alpha\left(1+\frac{1}{K_1}\right) - \left(\frac{\pi}{2}-\alpha\right)\left(1+\frac{1}{K_2}\right)}{\alpha\left(1+\frac{1}{K_1}\right) + \frac{d}{r}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)}\right]$$

The difference between the two expressions for M lies in first term of numerator, which for concentrated load is $\frac{1}{K_1}(1-\cos\alpha)$ and for distributed load $\frac{1}{K_1}\left(\frac{2\sin\alpha}{K} - \cos\alpha\right)$ For $\alpha = 0$ load must be concentrated and to expressions should be equal, canceling $\frac{1}{K_1}$ and substituting for K

$$1 - \cos\alpha = \frac{2\sin\alpha}{\alpha + \sin\alpha\cos\alpha} - \cos\alpha$$

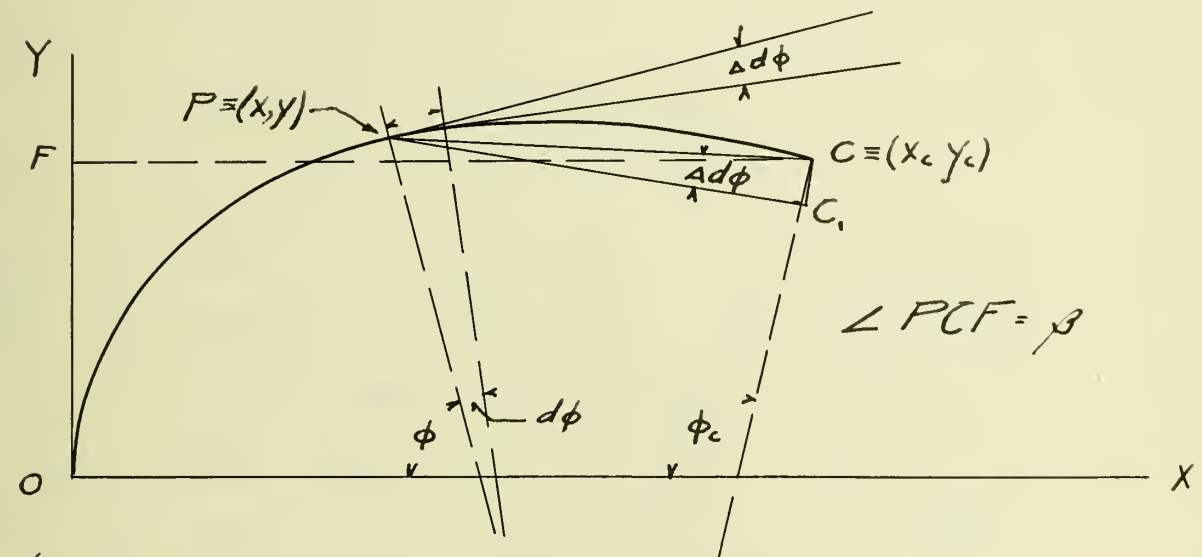
$$1 - 1 = \frac{2}{1+1} - 1 = 0$$

Difference between values of M as given by two equations is greatest when $\alpha = \frac{\pi}{2}$, and decreases with $\alpha$ becoming zero when $\alpha = 0$ that is when link has a circular center-line.

Tests and computations coming later will show that distribution as assumed makes a marked difference in stresses, or the parallel variable, the deformations.

## 3. Determinations of deformations.

The change in coordinates of the center-line of a curved link subjected to external forces is determined as follows, using same values of $w$, $E_0$, $\kappa$, $F$, $M_0$, $M$ and $Q$ as previously used or determined.




Let the curve shown be any center-line, P be any point on it, and C the point, the change in coordinates of which is to be found.

Let coordinates of C be $x_c$ and $y_c$ and the coordinate increments be denoted by $\Delta x_c$ and $\Delta y_c$ then the new coordinates of C will be

$$x_c + \Delta x_c$$

$$y_c + \Delta y_c$$

By action of the external forces the inclination

of a normal section at P will be changed by the angle $s\,d\phi$ and the tangent to the center-line at P will change its direction from PT to PT'. This change of angle will evidently cause point C to move through an arc of length $\rho_c s\,d\phi$ and assume position $C_1$.

X component of $CC_1$ is $CC_1 \sin\beta$

Y component is $CC_1 \cos\beta$

But $CC_1 = \rho_c s\,d\phi$ and $\rho_c \sin\beta = y - y_c$

and $\rho_c \cos\beta = x_c - x$

$\therefore$ X component is $(y - y_c)\,s\,d\phi$

Y component is $(x_c - x)\,s\,d\phi$

In addition to this, there is an increment due to the actual lengthening of an element of arc $ds$ at P. The amount of this extension is $\varepsilon_0\,ds$ hence by reason of it the point C is carried in the direction of the x axis a distance

$$\varepsilon_0\,ds \sin\phi = \varepsilon_0\,dx$$

and in direction of y axis a distance

$$\varepsilon_0\,ds \cos\phi = \varepsilon_0\,dy$$

Adding together the increments due to the change in direction, and the change in length of the elementary arc $ds$

$$d(\Delta x_c) = -(y - y_c)\,s\,d\phi + \varepsilon_0\,dx = y_c\,w\,d\phi - x\,w\,d\phi + \varepsilon_0\,dx$$

$$d(\Delta y_c) = -(x_c - x)\,s\,d\phi + \varepsilon_0\,dy = -x_c\,w\,d\phi + x\,w\,d\phi + \varepsilon_0\,dy$$

Summing for all the elementary arcs between C and the origin, or stationary point, at which $\phi = 0$

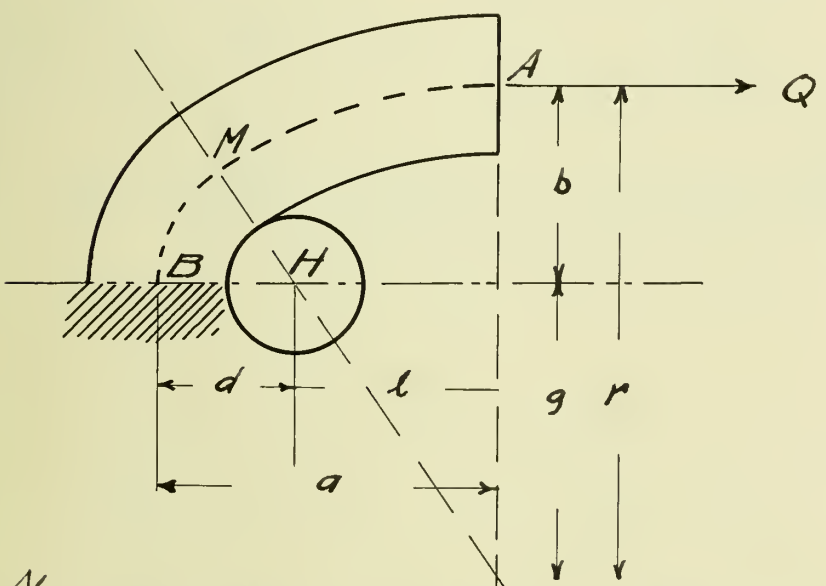
$$\Delta x_c = y_c \int_0^{\phi_c} w\,d\phi - \int_0^{\phi_c} y\,w\,d\phi + \int_0^{x_c} \varepsilon_0\,dx$$

$$\Delta y_c = -x_c \int_0^{\phi_c} w\,d\phi + \int_0^{\phi_c} x\,w\,d\phi + \int_0^{y_c} \varepsilon_0\,dy$$

a Four Arc Link.

Now applying above to the four arc, elliptical shaped link as shown below and represented in the tests by samples 1 and 5.

Elongations of major axis. Concentrated load.




Fundimental condition from above analysis is

$$\Delta x_c = (y_c - y) \int_0^{\phi_c} w\,d\phi + \int_0^{x_c} \varepsilon_0\,dx$$

Arc BM $\quad y = d \sin\phi$

Now $y_c = b$

MA $\quad y = r \sin\phi - g$

BM. $y_c - y = b - d\sin\phi$

MA $y_c - y = r(1-\sin\phi)$

$$Ef\,\varepsilon_{o_1} = \frac{M+Qb}{d} \qquad Ef\,\omega_1 = \frac{M+Qb}{d}\left(1+\frac{1}{n_1}\right) - \frac{Q}{n_1}\sin\phi$$

$$Ef\,\varepsilon_{o_2} = \frac{M}{r} + Q \qquad Ef\,\omega_2 = \frac{M}{r} + Q\left(1+\frac{1}{n_2}\right) - \frac{Q}{n_2}\sin\phi$$

Substituting and integrating

$$Ef\,\Delta = \alpha\frac{b}{d}(M+Qb)\left(1+\frac{1}{n_1}\right) - (M+Qb)\left(1+\frac{1}{n_1}\right)(1-\cos\alpha) - \frac{Qb}{n_1}(1-\cos\phi)$$

$$+ \frac{Qd}{2n_1}(\alpha - \sin\alpha\cos\alpha) + (M+Qr)\left(1+\frac{1}{n_2}\right)\left(\frac{\pi}{2}-\alpha\right)$$

$$-(M+Qr)\left(1+\frac{1}{n_2}\right)\cos\alpha - \frac{Qr}{n_2}\cos\alpha + \frac{Qr}{2n_2}(\alpha - \sin\alpha\cos\alpha)$$

In which M is the value previously derived in the work on stresses for a concentrated load on the four arc links.

$$M = Qd\left[\frac{\frac{1}{n_1}(1-\cos\alpha) + \frac{1}{n_2}\cos\alpha - \frac{b\alpha}{d}\left(1+\frac{1}{n_1}\right) - \left(\frac{\pi}{2}-\alpha\right)\left(1+\frac{1}{n_2}\right)}{\alpha\left(1+\frac{1}{n_1}\right) + \frac{d}{r}\left(\frac{\pi}{2}-\alpha\right)\left(1+\frac{1}{n_2}\right)}\right]$$

# Elongations of major axis, Four arc link. Distributed load.

Using same fundamental formula.

$$\Delta x_c = (y_c - y)\int_0^\phi \omega\, d\phi + \int_0^{x_c} \epsilon_0\, dx$$

$$x_c = b$$

BM $\quad y = d\sin\phi \qquad y_c - y = b - d\sin\phi$

MA $\quad y = r\sin\phi - g \qquad y_c - y = r(1-\sin\phi)$

$$Ef\,\epsilon_{0_1} = \frac{M+Qb}{d} \qquad Ef\,\omega_1 = \frac{M+Qb}{d}\left(1+\frac{1}{K_1}\right) - \frac{Q}{KK_1}(\sin^2\alpha\cos\phi + \phi\sin\phi)$$

$$Ef\,\epsilon_{0_2} = \frac{M}{r} + Q \qquad Ef\,\omega_2 = \left(\frac{M}{r}+Q\right)\left(1+\frac{1}{K_2}\right) - \frac{Q\sin\phi}{K_2}$$

Hence

$$\begin{aligned} Ef\,\Delta x_c = {} & \frac{b}{d}(M+Qb)\left(1+\frac{1}{K_1}\right)\int_0^\alpha d\phi - \frac{bQ}{KK_1}\sin^2\alpha\int_0^\alpha \cos\phi\, d\phi \\ & + \frac{bQ}{KK_1}\int_0^\alpha \phi\sin\phi\, d\phi + \frac{M+Qb}{d}\int_0^{d(1-\cos\alpha)} dx \\ & -(M+Qb)\left(1+\frac{1}{K_1}\right)\int_0^\alpha \sin\phi\, d\phi + \frac{Qd}{KK_1}\sin^2\alpha\int_0^\alpha \cos\phi\sin\phi\, d\phi \\ & + \frac{Qd}{KK_1}\int_0^\alpha \phi\sin^2\phi\, d\phi + \left(\frac{M}{r}+Q\right)\int_{d(1-\cos\alpha)}^{a} dx \\ & + (M+Qr)\left(1+\frac{1}{K_2}\right)\int_0^{\frac{\pi}{2}} d\phi - \frac{Qr}{K_2}\int_\alpha^{\frac{\pi}{2}} \sin\phi\, d\phi \\ & - (M+Qr)\left(1+\frac{1}{K_2}\right)\int_\alpha^{\frac{\pi}{2}} \sin\phi\, d\phi + \frac{Qr}{K_2}\int_\alpha^{\frac{\pi}{2}} \sin^2\phi\, d\phi \end{aligned}$$

Integrating this becomes.

$$Ef\,\Delta a = \alpha\frac{b}{d}(M+Qb)\left(1+\frac{1}{K_1}\right) + \frac{Qb}{K_1}\left(\frac{2\sin\alpha}{K} - \cos\alpha\right) -$$

$$- \frac{M+Qb}{K_1}(1-\cos\alpha) + \left(\frac{M}{r}+Q\right)[a - d(1-\cos\phi)]$$

$$+ \frac{Qd}{4K\,K_1}\left(2\sin^2\alpha + \alpha^2 - 2\alpha\sin\alpha\cos\alpha + \sin^2\alpha\right)$$

$$+ (M+Qr)\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right) - \frac{Qr}{K_2}\cos\alpha - (M+Qr)\left(1+\frac{1}{K_2}\right)\cos\alpha$$

$$+ \frac{Qr}{2K_2}(\alpha - \sin\alpha\cos\alpha)$$

In which $M$ is as previously derived for distributed load.

$$M = Qd\left[\frac{\frac{1}{K_1}\left(\frac{2\sin\alpha}{K} - \cos\alpha\right) + \frac{1}{K_2}\cos\alpha - \frac{b}{d}\alpha\left(1+\frac{1}{K_1}\right) - \left(\frac{\pi}{2}-\alpha\right)\left(1+\frac{1}{K_2}\right)}{\alpha\left(1+\frac{1}{K_1}\right) + \frac{d}{r}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)}\right]$$

Deformations of minor axis. Four arc link Concentrated load.

$$-\Delta y_c = (x_c - x)\int \omega\, d\phi \qquad \int \varepsilon_0\, dy$$

Arc BM $\quad x = d(1-\cos\phi) \qquad x_c - x = a - d(1-\cos\phi)$

MA. $\quad x = a - r\cos\phi \qquad x_c - x = r\cos\phi$

$$Ef\,\varepsilon_{01} = \frac{M+Qb}{d} \qquad Ef\,\omega_1 = \frac{M+Qb}{d}\left(1+\frac{1}{K_1}\right) - \frac{Q}{K_1}\sin\phi$$

$$Ef\,\varepsilon_{02} = \frac{M}{r} + Q \qquad Ef\,\omega_2 = \left(\frac{M}{r}+Q\right)\left(1-\frac{1}{K_2}\right) - \frac{Q}{K_2}\sin\phi$$

Then

$$-\Delta y_c = (a-d)\frac{M+Qb}{d}\left(1+\frac{1}{H_1}\right)\int_0^{\alpha} d\phi - (a-d)\frac{Q}{H_1}\int_0^{\alpha}\sin\phi\, d\phi$$

$$-(M+Qb)\left(1+\frac{1}{H_1}\right)\int_0^{\alpha}\cos\phi\, d\phi + \frac{Qd}{H_1}\int_0^{\alpha}\sin\phi\cos\phi\, d\phi$$

$$+(M+Qr)\left(1+\frac{1}{H_2}\right)\int_{\alpha}^{\frac{\pi}{2}}\cos\phi\, d\phi - \frac{Qr}{H_2}\int_{\alpha}^{\frac{\pi}{2}}\sin\phi\cos\phi\, d\phi - (M+Qb)\sin\alpha$$

$$-\left(\frac{M}{r}+Q\right)(b-d\sin\alpha$$

Integrating and transposing

$$-E\!f\Delta b = M\left[\left(1+\frac{1}{H_1}\right)\left(\alpha\frac{e}{d}-\sin\alpha\right)+\left(1+\frac{1}{H_2}\right)(1-\sin\alpha)-\sin\alpha-\frac{b}{r}\right.$$

$$\left.+\frac{d}{r}\sin\alpha\right] + Qd\left[\left(\alpha\frac{e}{d}-\sin\alpha\right)\left(1+\frac{1}{H_1}\right)\frac{b}{d}-\frac{e}{dH_1}(1-\cos\alpha)\right.$$

$$-\frac{b}{d}\left(1+\frac{1}{H_1}\right)\sin\alpha+\frac{d}{2H_1}\sin\alpha+\frac{r}{d}\left(1+\frac{1}{H_2}\right)(1-\sin\alpha)$$

$$\left.-\frac{r}{2dH_2}(1-\sin\alpha)-\frac{b}{d}\sin\alpha-\frac{b}{d}+\sin\alpha\right]$$

In which $M = Qd\left[\dfrac{\frac{1}{H_1}(1-\cos\alpha)+\frac{1}{H_2}\cos\alpha-\frac{b}{d}\alpha\left(1+\frac{1}{H_1}\right)-\left(1+\frac{1}{H_2}\right)\left(\frac{\pi}{2}-\alpha\right)}{\alpha\left(1+\frac{1}{H_1}\right)+\frac{d}{r}\left(1+\frac{1}{H_2}\right)\left(\frac{\pi}{2}-\alpha\right)}\right]$

Deformations of minor axis. Four arc link. Distributed load.

On page (42) of J. A. Goodenoughs work we find the derivation for this case

$$M = \frac{\Psi}{\Gamma} \quad \text{and} \quad -E\!f\Delta b = \Omega M + X Qd$$

Where

$$\Psi = \frac{b}{d}\left(1+\frac{1}{\mu_1}\right)\alpha + \left(1+\frac{1}{\mu_2}\right)\left(\frac{\pi}{2}-\alpha\right) - \frac{\cos\alpha}{\mu_2} - \frac{1}{\mu_1}\left(\frac{2\sin\alpha}{\pi} - \cos\alpha\right)$$

$$\Gamma = \alpha\left(1+\frac{1}{\mu_1}\right) + \frac{d}{\mu}\left(1+\frac{1}{\mu_2}\right)\left(\frac{\pi}{2}-\alpha\right)$$

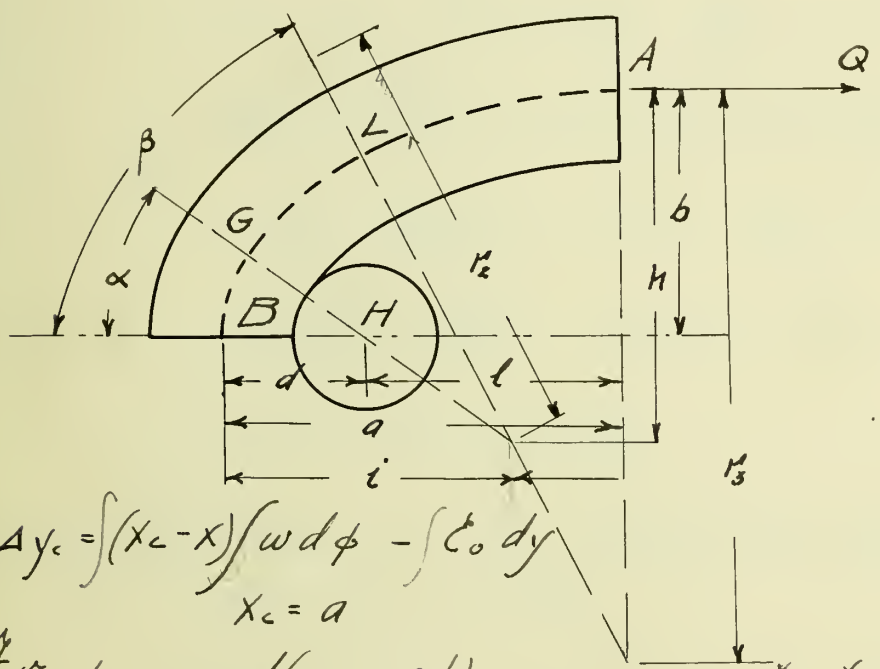
$$\Omega = \frac{b}{d}\left(1+\frac{1}{\mu_1}\right)\alpha - \sin\alpha\left(\frac{1}{\mu_2}-\frac{1}{\mu_1}\right) + \frac{1}{\mu_2}$$

$$X = \frac{1}{\mu_1}\left(\frac{b}{d}\sin\alpha - \frac{\sin^2\alpha}{2} - \frac{1}{4}\right) - \frac{b}{d\mu_1}\left(\frac{2\sin\alpha}{\pi} - \cos\alpha\right) + \frac{\alpha}{2K\mu_1}\cos^2\alpha$$
$$+ \frac{bb}{dd}\alpha\left(1+\frac{1}{\mu_1}\right) + \frac{\mu}{2d\mu_2}(1-\sin\alpha)^2$$

## Six arc link Distributed load

Experience with calculations on sample 5 showed that the four arc approximation gave more distribution than really existed hence, six arcs were substituted as shown in sketch of sample 5 being made small enough to cover only range of contact as shown there. The following is the derivation of this form.

## Six arc. Distributed load
## Deformations of linear axis.




$$-\Delta y_c = \int (x_c - x) \int w \, d\phi - \int \varepsilon_0 \, dy$$

$x_c = a$

For $\alpha$ $\quad x = d(1 - \cos\phi)$ $\quad\quad x_c - x = a - d(1 - \cos\phi)$

$\alpha$ to $\beta$ $\quad x = i - r_2 \cos\phi$ $\quad\quad x_c - x = a - i + r_2 \cos\phi$

$\beta$ to $\frac{\pi}{2}$ $\quad x = a - r_3 \cos\phi$ $\quad\quad x_c - x = r_3 \cos\phi$

$$Ef\,\xi_{o1} = \frac{M+Qb}{d} \qquad Ef\,\omega_1 = \frac{M+Qb}{d}\left(1+\frac{1}{K_1}\right) - \frac{Q}{KK_1}\left(\sin^2\alpha\cos\phi + \phi\sin\phi\right)$$

$$Ef\,\xi_{o2} = \frac{M+Qh}{r_2}( \qquad Ef\,\omega_2 = \frac{M+Qh}{r_2}\left(1+\frac{1}{K_2}\right) - \frac{Q}{K_2}\sin\phi$$

$$Ef\,\xi_{o3} = \frac{M}{r_3} + Q \qquad Ef\,\omega_3 = \frac{M+Qr_3}{r_3}\left(1+\frac{1}{K_3}\right) - \frac{Q}{K_3}\sin\phi$$

$$\alpha \qquad M_b = M + Qb - \frac{Qd}{K}\left(\sin^2\alpha\cos\phi + \phi\sin\phi\right)$$

$$\alpha \text{ to } \beta \qquad = M + Q\left(h - r_2\sin\phi\right)$$

$$\beta \text{ to } \frac{\pi}{2} \qquad = M + Qr_3\left(1-\sin\phi\right)$$

Substituting

$$-Ef\,\Delta b = \frac{d(a-\alpha)}{d}(M+Qb)\left(1+\frac{1}{K_1}\right)\int_0^\alpha d\phi + (M+Qb)\left(1+\frac{1}{K_1}\right)\int_0^\alpha \cos\phi\,d\phi$$

$$+\frac{(a-i)}{r_2}\left(1+\frac{1}{K_2}\right)(M+Qh)\int_\alpha^\beta d\phi + (M+Qh)\left(1+\frac{1}{K_2}\right)\int_\alpha^\beta \cos\phi\,d\phi$$

$$+(M+Qr_3)\left(1+\frac{1}{K_3}\right)\int_\beta^{\frac{\pi}{2}} \cos\phi\,d\phi - (a-d)\frac{Q}{KK_1}\sin^2\alpha\int_0^\alpha \cos\phi\,d\phi$$

$$-(a-d)\frac{Q}{KK_1}\int_0^\alpha \phi\sin\phi\,d\phi - \frac{Qd}{KK_1}\sin^2\alpha\int_0^\alpha \cos^2\phi\,d\phi$$

$$-\frac{Qd}{KK_1}\int_0^\alpha \phi\sin\phi\cos\phi\,d\phi - (a-i)\frac{Q}{K_2}\int_\alpha^\beta \sin\phi\,d\phi$$

$$-\frac{Qr_2}{K_2}\int_\alpha^\beta \sin\phi\cos\phi\,d\phi - \frac{Qr_3}{K_3}\int_\beta^{\frac{\pi}{2}} \sin\phi\cos\phi\,d\phi$$

$$-\frac{M+Qb}{d}\cdot d\sin\alpha - MhQh\left(\sin\beta - \sin\alpha\right)$$

$$-(M+Qr_3)\left(1-\sin\beta\right)$$

M for this case is the distributed load M of the previous four arc links

$$M = Qd\left[\frac{\frac{1}{K_1}\left(\frac{2\sin\alpha}{K} - \cos\alpha\right) + \frac{1}{K_2}\cos\alpha - \frac{b}{d}\alpha\left(1+\frac{1}{K_1}\right) - \left(\frac{\pi}{2}-\alpha\right)\left(1+\frac{1}{K_2}\right)}{\alpha\left(1+\frac{1}{K_1}\right) + \frac{d}{r_2}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)}\right]$$

Integrating

$$-Eftab = (M+Qb)\left(1+\frac{1}{n_1}\right)\alpha\frac{l}{d} + (M+Qb)\frac{\sin\alpha}{n_1}$$

$$+\frac{a-i}{n_2}\left(1+\frac{1}{n_2}\right)(\beta-\alpha)(M+Qh) + (M+Qh)\frac{\sin\beta-\sin\alpha}{n_2}$$

$$+(M+Qh_3)\frac{1-\sin\beta}{n_3} - \frac{Ql}{n_1}\left(\frac{2\sin\alpha}{k}-\cos\alpha\right) - \frac{Qd}{4n_1}\left(2\sin^2\alpha+1\right)$$

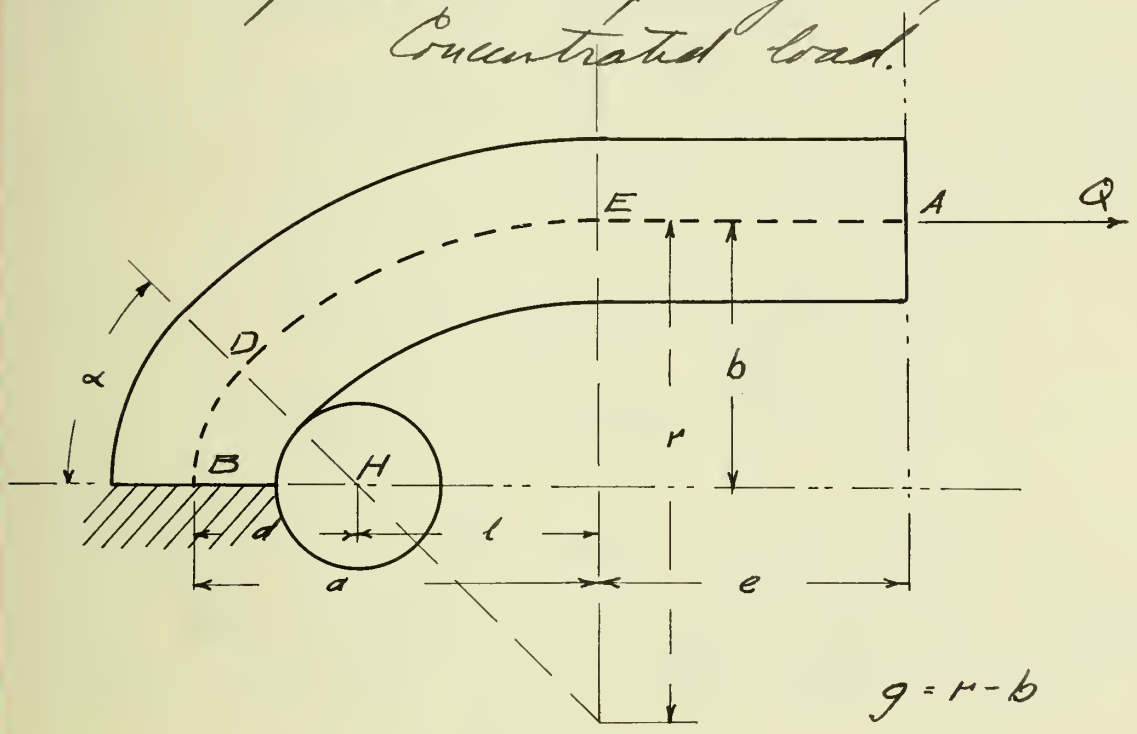
$$+\frac{Qd}{2kn_1}\alpha\cos^2\alpha - \frac{(q-i)Q}{n_2}(\cos\alpha-\cos\beta) - \frac{Qh_3}{2n_2}(\sin^2\beta-\sin^2\alpha)$$

$$-\frac{Qh_3}{2n_3}(1-\sin^2\beta)$$

# Four arc and straight side link.

This type is represented by samples z and 4. Computations being made on z.

## Deformations of major axis. Concentrated load.




First $\Delta x_c = (y_c - y)\int_0^{\phi} \omega d\phi + \int_0^{x_c} \varepsilon_0 dx$

$y_c = b$

| | | |
|---|---|---|
| BD | $y = d \sin\phi$ | $y_c - y = b - d\sin\phi$ |
| DE | $y = r\cos\phi - g$ | $y_c - y = r(1 - \sin\phi)$ |
| EA | $y = b$ | $y_c - y = 0$ |

BD $Ef\,\varepsilon_{o_1} = \frac{M+Qb}{A}$ $\quad Ef\,\omega_1 = \frac{M+Qb}{A}\left(1+\frac{1}{K_1}\right) - \frac{Q}{K_1}\sin\phi$

DE $Ef\,\varepsilon_{o_2} = \frac{M}{r}+Q$ $\quad Ef\,\omega_2 = \left(\frac{M}{r}+Q\right)\left(1+\frac{1}{K_2}\right) - \frac{Q}{K_2}\sin\phi$

EA $Ef\,\varepsilon_{o_3} = Q$ $\quad Ef\,\omega_3 = 16\,M\frac{\rho}{A_2}$ ,

Substituting and integrating

$$Ef\,\Delta a = \alpha\frac{b}{A}(M+Qb)\left(1+\frac{1}{K_1}\right) - (M+Qb)\left(1+\frac{1}{K_1}\right)(1-\cos\alpha) - \frac{Qb}{K_1}(1-\cos\phi)$$

$$+\frac{Qd}{2K_1}(\alpha - \sin\alpha\cos\alpha) + (M+Qr)\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)$$

$$-(M+Qr)\left(1+\frac{1}{K_2}\right)\cos\alpha - \frac{Qr}{K_2}\cos\alpha$$

$$+\frac{Qr}{2K_2}(\alpha - \sin\alpha\cos\alpha) + Qc$$

In which M is the same as for four arc link with term added to account for the change in moment arm due to the added length c.

$$M = Qd\left[\frac{\frac{1}{K_1}(1-\cos\alpha) + \frac{1}{K_2}\cos\alpha - \frac{b}{A}\alpha\left(1+\frac{1}{K_1}\right) - \left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)}{\alpha\left(1+\frac{1}{K_1}\right) + \frac{d}{r}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right) + 16\frac{c}{d}}\right]$$

Deformations of major axis.
Distributed load.

$$\Delta X_c = \int_0^{\phi} y_c - y \, w \, d\phi + \int_0^{x_c} \varepsilon_0 \, dx$$

$$y_c = b$$

BD $y = d \sin\phi$ $\qquad y_c - y = b - d\sin\phi$

DE $y = r\cos\phi - g$ $\qquad y_c - y = r(1 - \sin\phi)$

EA $y = b$ $\qquad y_c - y = 0$

$$Ef\varepsilon_{01} = \frac{M+Qb}{d} \qquad Efw_1 = \frac{M+Qb}{d}\left(1+\frac{1}{K_1}\right) - \frac{Q}{KK_1}\left(\sin^2\alpha\cos\phi + \phi\sin\phi\right)$$

$$Ef\varepsilon_{02} = \frac{M}{r} + Q \qquad Efw_2 = \left(\frac{M}{r}+Q\right)\left(1+\frac{1}{K_2}\right) - \frac{1}{K_2} Q\sin\phi$$

$$Ef\varepsilon_{03} = Q \qquad Efw_3 = 16\frac{Mp}{d^2}$$

From the above it is evident that the substitution will be the same as for the short link plus the following terms.

$$\int_0^e \varepsilon_{03}\, dx = \int_0^e Q\, dx = Qe$$

and

$$\int_0^{\phi} y_c - y \, w \, d\phi$$ for length e which reduces to 0.

Hence

$$Ef\Delta a = \alpha\frac{b}{d}(M+Qb)\left(1+\frac{1}{\mu_1}\right)+\frac{Qb}{\mu_1}\left(\frac{2\sin\alpha}{\kappa}-\cos\alpha\right)$$

$$-\frac{M+Qb}{\mu_1}(1-\cos\alpha)+\left(\frac{M}{r}+Q\right)[a-d(1-\cos\phi)]$$

$$+\frac{Qd}{4K\mu_1}\left(2\sin^2\alpha+\alpha^2-2\alpha\sin\alpha\cos\alpha+\sin^2\alpha\right)$$

$$+(M+Qr)\left(1+\frac{1}{\mu_2}\right)\left(\frac{\pi}{2}-\alpha\right)-\frac{Qr}{\mu_2}\cos\alpha-(M+Qr)\left(1+\frac{1}{\mu_2}\right)\cos\alpha$$

$$+\frac{Qr}{2\mu_2}(\alpha-\sin\alpha\cos\alpha)+Qe$$

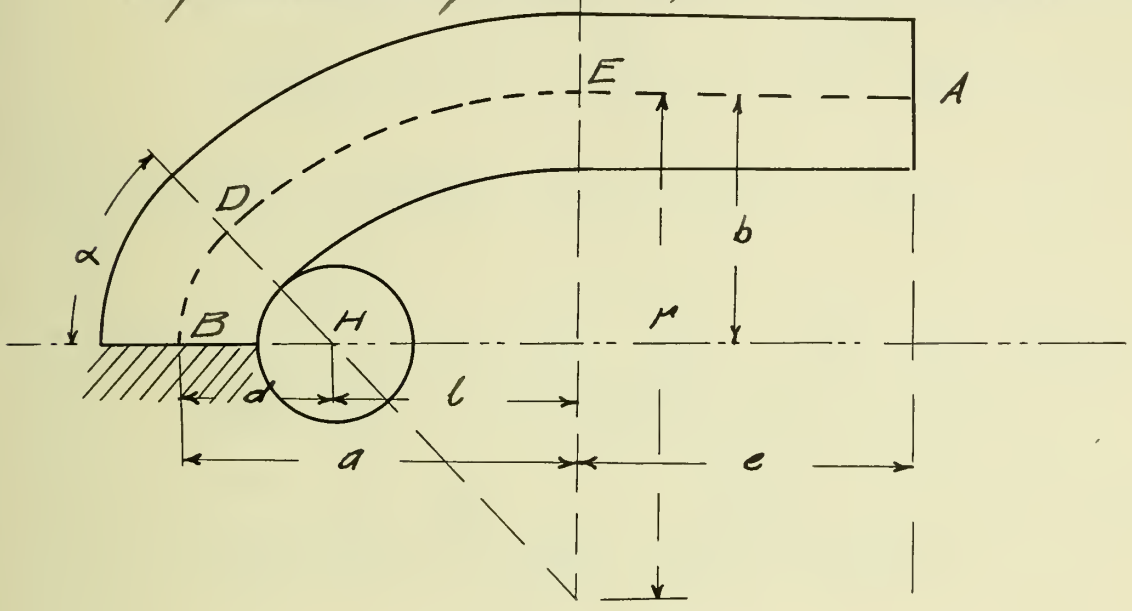
In which M is as follows, being same as for four arc ling plus term added to denominator to account for the reduction due to lengthening the moment arm by the straight side.

$$M = Qd\left[\frac{\frac{2\sin\alpha}{K\mu_1}-\frac{1}{\mu_1}\cos\alpha+\frac{1}{\mu_2}\cos\alpha-\frac{b}{d}\alpha\left(1+\frac{1}{\mu_1}\right)-\left(1+\frac{1}{\mu_2}\right)\left(\frac{\pi}{2}-\alpha\right)}{\alpha\left(1+\frac{1}{\mu_1}\right)+\frac{d}{r}\left(1+\frac{1}{\mu_2}\right)\left(\frac{\pi}{2}-\alpha\right)+1\zeta\frac{c}{d}}\right]$$

# Four arc and straight side link.

This type is represented in the tests by samples 2 and 4.

Deformations of minor axis. Concentrated load.




To evaluate $-\Delta y_c = \int_0^{\alpha} (x_c - x) \int_0^{\phi_c} \omega \, d\phi - \int_0^{y_c} \varepsilon_0 \, dy$

For arc $x_c = a + e$

| | | |
|---|---|---|
| BD | $x = d(1-\cos\phi)$ | $x_c - x = a + e - d + d\cos\phi$ |
| DE | $x = a - r\cos\phi$ | $x_c - x = e + r\cos\phi$ |
| EA | $x = a + e - z$ | $x_c - x = z$ |

$$BD,\ Ef\varepsilon_{o_1} = \frac{M + Qb}{d} \qquad Ef\omega_1 = \frac{M + Qb}{d}\left(1 + \frac{1}{\chi_1}\right) - \frac{Q}{\chi_1}\sin\phi$$

$$DE,\ Ef\varepsilon_{o_2} = \frac{M}{r} + Q, \qquad Ef\omega_2 = \left(\frac{M}{r} + Q\right)\left(1 + \frac{1}{\chi_2}\right) - \frac{Q}{\chi_2}\sin\phi$$

$$EA,\ Ef\varepsilon_{o_3} = Q + \frac{M}{\rho} = Q; \quad \omega_3 = Q + \frac{M}{\rho} + \frac{M}{\chi_3\rho} = M \cdot \frac{16\rho^2}{d} = 16M\frac{\rho}{d^2}$$

$$P = Q \qquad M_b = M$$

Now substituting

$$-\Delta y_c = (a+e-d)\frac{M+Qb}{d}\left(1+\frac{1}{K_1}\right)\int_0^\alpha d\phi - (a+e-d)\frac{Q}{K_1}\int_0^\alpha \sin\phi\, d\phi$$
$$-(M+Qb)\left(1+\frac{1}{K_1}\right)\int_0^\alpha \cos\phi\, d\phi + \frac{Qd}{K_1}\int_0^\alpha \sin\phi\cos\phi\, d\phi$$
$$+e\left(\frac{M}{r}+Q\right)\left(1+\frac{1}{K_2}\right)\int_\alpha^{\frac{\pi}{2}} d\phi - \frac{Qe}{K_2}\int_\alpha^{\frac{\pi}{2}} \sin\phi\, d\phi$$
$$+(M+Qr)\left(1+\frac{1}{K_2}\right)\int_\alpha^{\frac{\pi}{2}} \cos\phi\, d\phi - \frac{Qr}{K_2}\int_\alpha^{\frac{\pi}{2}} \sin\phi\cos\phi\, d\phi$$
$$+\frac{16M}{d^2}\int_0^\alpha z\rho\, d\phi - (M+Qb)\sin\alpha - \left(\frac{M}{r}+Q\right)(b-d\sin\alpha)$$

Integrating letting $h = a+e-d = l+e$,

$$\Delta b = \alpha\frac{h}{d}(M+Qb)\left(1+\frac{1}{K_1}\right) - \frac{Qh}{K_1}(1-\cos\alpha) - (M+Qb)\left(1+\frac{1}{K_1}\right)\sin\alpha$$
$$+\frac{Qd}{2K_1}\sin^2\alpha + e\left(\frac{M}{r}+Q\right)\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right) - \frac{Qe}{K_2}\cos\alpha$$
$$+(M+Qr)\left(1+\frac{1}{K_2}\right)(1-\sin\alpha) - \frac{Qr}{2K_2}(1-\sin\alpha) + 8M\frac{e^2}{d^2}$$
$$-(M+Qb)\sin\alpha - \left(\frac{M}{r}+Q\right)(b-d\sin\alpha)$$

$$= M\left[\left(1+\frac{1}{K_1}\right)\left(\alpha\frac{h}{d}-\sin\alpha\right) + \frac{e}{r}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right) + \left(1+\frac{1}{K_2}\right)(1-\sin\alpha)\right.$$
$$\left.+8\frac{e^2}{d^2} - \sin\alpha - \frac{b}{r} + \frac{d}{r}\sin\alpha\right]$$

$$+Qd\left[\left(\alpha\frac{h}{d}-\sin\alpha\right)\left(1+\frac{1}{K_1}\right)\frac{b}{d} - \frac{h}{dK_1}(1-\cos\alpha) - \frac{b}{d}\left(1+\frac{1}{K_1}\right)\sin\alpha\right.$$
$$+\frac{d}{2K_1}\sin\alpha + \frac{e}{d}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right) - \frac{e}{dK_2}\cos\alpha + \frac{r}{d}\left(1+\frac{1}{K_2}\right)(1-\sin\alpha)$$
$$\left.-\frac{r}{2dK_2}(1-\sin\alpha) - \frac{b}{d}\sin\alpha - \frac{b}{d} + \sin\alpha\right]$$

and M is given by the following.

$$M - Qd\left[\frac{\frac{1}{K_1}(1-\cos\alpha) + \frac{1}{K_2}\cos\alpha - \frac{b}{d}\alpha\left(1+\frac{1}{K_1}\right) - \left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)}{\alpha\left(1+\frac{1}{K_1}\right) + \frac{d}{r}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right) + 16\frac{e}{d}}\right]$$

For the same link (four arc and straight sides) The deformations of the minor axis, distributed load are as follows.

$$X_c = a + e$$

BD $x = d(1-\cos\phi)$ $\qquad X_c - x = a + e - d + d\cos\phi$

DE $x = a - r\cos\phi$ $\qquad X_c - x = e + r\cos\phi$

EA $x = a + e - z$ $\qquad X_c - x = z$

BD $Ef\varepsilon_{o_1} = \frac{M+Qb}{d}$ $\qquad Ef\omega_1 = \frac{M+Qb}{d}\left(1+\frac{1}{K_1}\right) - \frac{Q}{KK_1}\left(\sin^2\alpha\cos\phi + \phi\sin\phi\right)$

BE $Ef\varepsilon_{o_2} = \frac{M}{r} + Q$ $\qquad Ef\omega_2 = \left(\frac{M}{r}+Q\right)\left(1+\frac{1}{K_2}\right) - \frac{Q\sin\phi}{K_2}$

EA $Ef\varepsilon_{o_3} = Q + \frac{M}{\rho} = Q$ $\qquad Ef\omega_3 = Q + \frac{M}{\rho} + 16\frac{\rho M}{d^2} = 16\frac{M\rho}{d^2}$

Substitution is as follows.

$$-Ef\Delta b = (M+Qb)\left(1+\frac{1}{K_1}\right)\frac{\alpha l}{d} - \frac{Ql}{KK_1}\sin^2\alpha - \frac{Ql}{KK_1}(\sin\alpha - \alpha\cos\alpha)$$

$$-(M+Qb)\left(1+\frac{1}{K_1}\right)\sin\alpha - \frac{Qd}{2K_1}\sin^2\alpha$$

$$-\frac{Qd}{4KK_1}(2\sin^2\alpha + \sin\alpha\cos\alpha - \alpha) + \left(M+Qr\right)\left(1+\frac{1}{K_2}\right)(1-\sin\alpha)$$

$$-\frac{Qr}{2K_2}\cos^2\alpha - (M+Qb)\sin\alpha - \left(\frac{M}{r}+Q\right)(b-d\sin\alpha)$$

$$+\left(\frac{M}{r}+Q\right)\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)e + \frac{Qe}{K_2}\cos\alpha + 8M\frac{e^2}{d^2}$$

Further reduction gives this as final form.

$$-E f_{ab} = M\left[\alpha\frac{e}{d}\left(1+\frac{1}{K_1}\right)+\left(1+\frac{1}{K_1}\right)\sin\alpha+\left(1+\frac{1}{K_2}\right)(1-\sin\alpha)-\sin\alpha\right.$$

$$\left.-\frac{b}{r}+\frac{d}{r}\sin\alpha+\frac{e}{r}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)+\delta\frac{e^2}{d^2}\right]$$

$$+Qd\left[\alpha\frac{bl}{d^2}\left(1+\frac{1}{K_1}\right)-\frac{l}{dK_1}\left(\frac{2\sin\alpha}{K}-\cos\alpha\right)\right.$$

$$+\frac{b}{dK_1}\sin\alpha-\frac{1}{2K_1}\sin^2\alpha-\frac{1}{4KK_1}\left(2\sin^2\alpha+\cos\alpha\sin\alpha-\alpha\right)$$

$$+\frac{r}{d}\left(1+\frac{1}{K_2}\right)(1-\sin\alpha)-\frac{r}{2dK_2}\cos^2\alpha-\frac{b}{d}+\sin\alpha$$

$$\left.+\frac{e}{d}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)-\frac{e}{dK_2}\cos\alpha\right]$$

This is taken almost entirely from original page 41, by making S the reaction of the stud gun and adding terms to account for the straight side a.

Moment M is the same as used previously for a distributed load

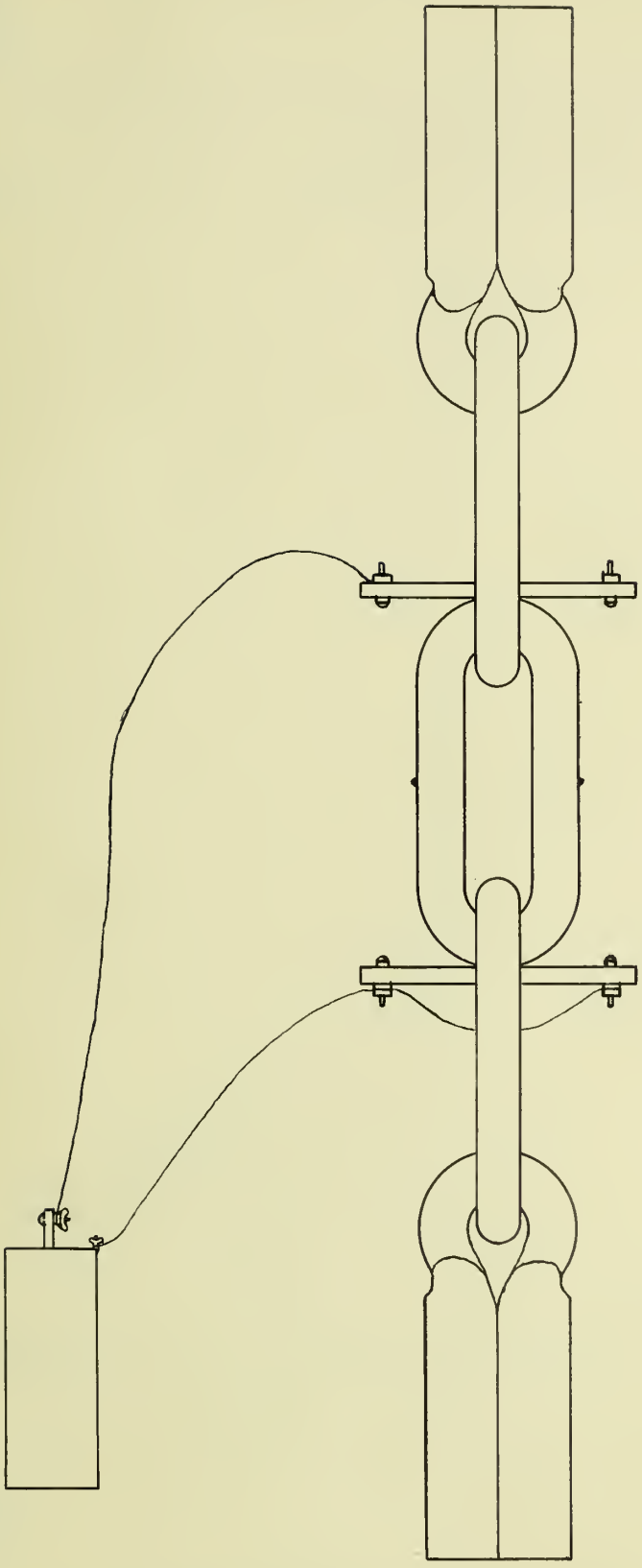
$$M = Qd\left[\frac{\frac{2}{K}\sin\alpha-\frac{1}{K_1}\cos\alpha+\frac{1}{K_2}\cos\alpha-\frac{b}{d}\alpha\left(1+\frac{1}{K_1}\right)-\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)}{\alpha\left(1+\frac{1}{K_1}\right)+\frac{d}{r}\left(1+\frac{1}{K_2}\right)\left(\frac{\pi}{2}-\alpha\right)+16\frac{e}{d}}\right]$$

## IV Description of Tests.

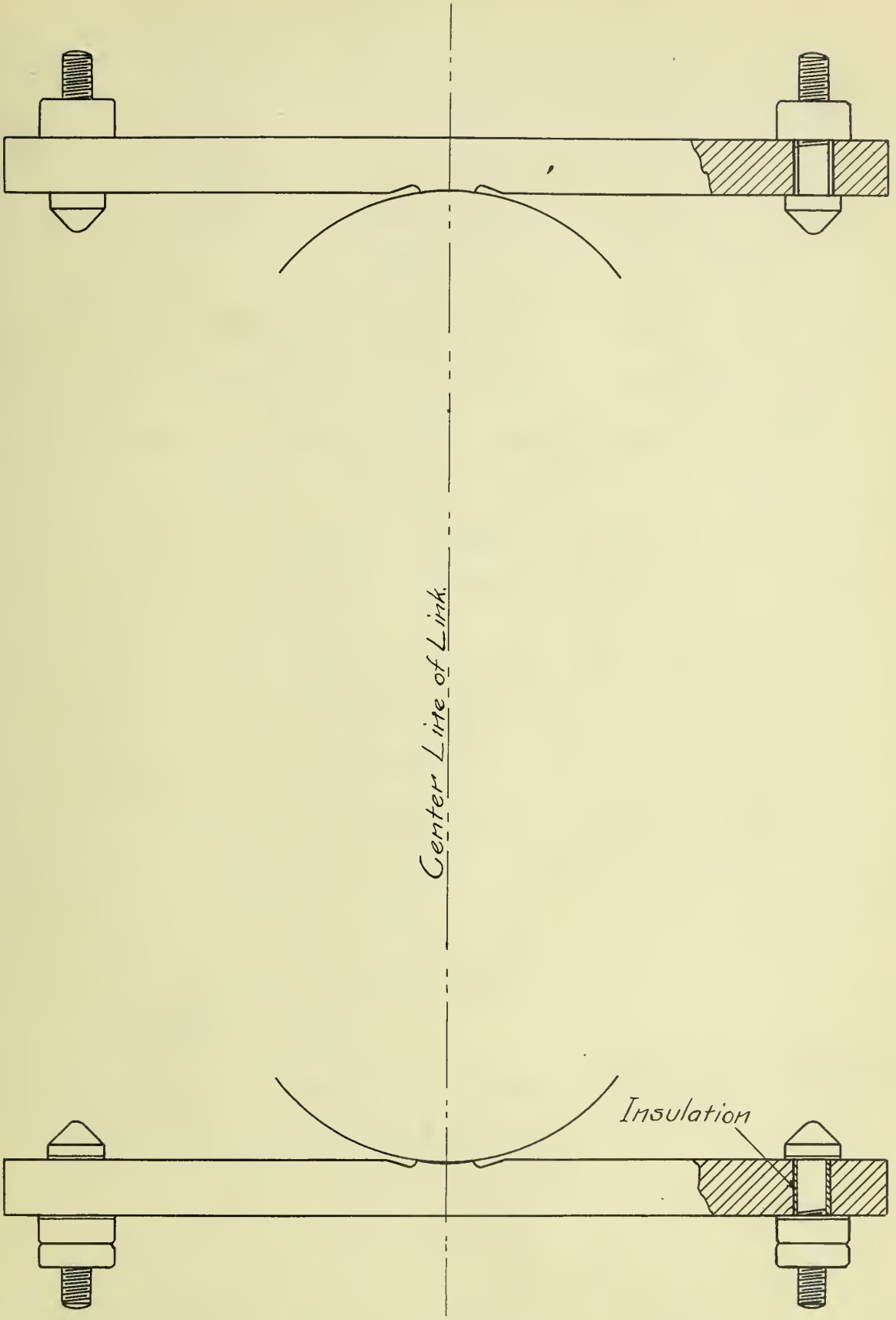
1. Samples 1-2-3 were obtained from Newhall Iron Chain & Forge Co, correspondence being conducted with the New York office in Murray building. Links and bar samples of stock came from the Seneca Iron Works Kent Ohio, nearly three month after correspondence was opened with New York office. The second set of samples 4-5-6 came from the stock of Jones, Laughlin and Co, Pittsburg. These were sent as a gift in return to a letter through Burr and Co asking for prices on the same.

While waiting for samples time was devoted to constructing an extensometer. This consisted of two microscopes mounted on guides, and moved with graduated micrometer screws. Guides carrying microscopes were clamped in between head and platform of machine. This mechanism would have read deformations direct but could not be used, because the focal range of the microscopes was so small that they frequently required adjustment, or focusing. This it was found ruined the readings. Hence the instrument was discarded.

Fig #1.



Sketch of Extensometer


Center Line of Link.
Insulation

2. The final method of testing was as follows. Heavy irons as shown, were forged into first and third links of sample, Then extensometer bars screwed on to ends of second link and brass caliper points on the sides The sample was then ready for testing.

The U shaped pieces on links one and three were clamped in machine, caliper tips screwed into extensometer bars and electric bell connected. Initial load was then put on and zero readings taken, front and back with inside calipers between tips on extensometer bars and then across the caliper points on sides with outside calipers. Loading and reading was continued until deformations showed link had reached elastic limit of the material. It was then removed from machine rested for two or three days and a check test was run in the same manner.

3. Actual Tests

| Sample | Company | Material | Link | Coef. of E. Test No. | Deformation Test No. |
|---|---|---|---|---|---|
| 1 | N.I.C.&F.Co | Seneca Special | Dredge | 1 | 8 |
| 2 | | Com. Iron | Conveyor | 2 | 4 |
| 3 | | B.B. Iron | Stud | 3 | 5 |
| 4 | J.&L.Co | Steel | Proof Coil | 10 | 7 |
| 5 | | Iron | Dredge | 11 | 6 |
| 6 | | Iron | Stud | 12 | 9 |

Tests 1-2-3-10-11-12 are Coef. of Elasticity tests made in the ordinary manner, a new Riehle electric contact extensometer being used. Data and curve sheets show results in full.

Tests 4-5-6-7-8-9 were the tests on links themselves. Curve sheets show that results are uniform, much more so than could be expected for all of the differences are in .0001 ths of an inch, which place had to be interpolated calipers reading direct only to .001 of an inch. That no juggling of results occured is guaranteed from the fact that L.E. Moore, instructor in Mechanics of Materials assisted on tests by taking down all data as measured.

4. Deformations measured from average curve as drawn should be absolutely accurate to the fourth place, since they are an average of results absolutely accurate to the third place, with the added advantage over the ordinary average, that exceptionaly bad points have no effect.

Sample #2

Computations on Conveyor Link.
Four arcs and straight sides. Concentrated load

| | | | |
|---|---|---|---|
| $\alpha = 1.0984$ | $\frac{1}{\mu_1} = 13.93$ | $r = 3.125$ | $l = 1.$ |
| $\sin\alpha = .8824$ | $\frac{1}{\mu_2} = 154.25$ | $a = 2.$ | $d = 1$ |
| $\cos\alpha = .4705$ | $h = a+e-d = 3.5$ | $b = 1.25$ | $e = 1.5$ |

Value of M.

| Term | Substitution | Result |
|---|---|---|
| $+\frac{1}{\mu_1}(1-\cos\alpha)$ | $+13.93 \times .5295$ | 7.3759 |
| $+\frac{1}{\mu_2}(\cos\alpha)$ | $+154.25 \times .4705$ | 72.5746 |
| $-\frac{b}{d}\alpha(1+\frac{1}{\mu_1})$ | $-1.25 \times 1.0984 \times 14.93$ | 20.4988 |
| $-(1+\frac{1}{\mu_2})(\frac{\pi}{2}-\alpha)$ | $-153.25 \times .4724$ | 73.3401 |
| | | 79.9505 93.8389 |
| | | 79.9505 |
| Numerator of M. | | -13.8884 |

| | | |
|---|---|---|
| $+\alpha(1+\frac{1}{\mu_1})$ | $+1.0984 \times 14.93$ | 16.3991 |
| $+\frac{d}{r}(1+\frac{1}{\mu_2})(\frac{\pi}{2}-\alpha)$ | $+\frac{153.25 \times .4724}{3.125}$ | 23.3176 |
| $+16\frac{e}{d}$ | $+16 \times 1.5$ | 24 |
| Denominator of M. | | 63.7167 |

$$M = \frac{-13.8884}{63.7167} = -.21797$$ Ans

## Coef of M.

| Term | Substitution | Results. | |
|---|---|---|---|
| $+(1+\frac{1}{X_1})(\alpha\frac{h}{d}-\sin\alpha)$ | $+14.93(1.0984\times3.5-.8824)$ | 44.2327 | |
| $+\frac{e}{\mu}(1+\frac{1}{X_2})(\frac{\pi}{2}-\alpha)$ | $\frac{1.5}{3.125}\times155.25\times.4724$ | 35.2032 | |
| $+(1+\frac{1}{X_2})(1-\sin\alpha)$ | $+155.25\times.1176$ | 18.2574 | |
| $+8\frac{e^2}{d^2}$ | $+.8\times2.25$ | 18. | |
| $-\sin\alpha$ | $-.8824$ | | .8824 |
| $-\frac{b}{\mu}$ | $-\frac{1.25}{3.125}$ | | .4 |
| $+\frac{d}{\mu}\sin\alpha$ | $+\frac{.8824}{3.125}$ | | .2824 |
| | | 115.9757 | 1.2824 |
| | | 1.2824 | |
| Coef of M. | | 114.6933 | |

## Coef of Q

| | | | |
|---|---|---|---|
| $+(\alpha\frac{h}{d}-\sin\alpha)(1+\frac{1}{X_1})\frac{b}{d}$ | $+(1.0984\times3.5-.8824)14.93\times1.25$ | 55.2787 | |
| $-\frac{h}{dX_1}(1-\cos\alpha)$ | $-3.5\times13.93\times.5295$ | | 25.8157 |
| $-\frac{b}{d}(1+\frac{1}{X_1})\sin\alpha$ | $-1.25\times14.93\times.8824$ | | 16.4673 |
| $+\frac{d}{2X_1}\sin\alpha$ | $+\frac{13.93\times.4705}{2}$ | 3.2770 | |
| $+\frac{e}{d}(1+\frac{1}{X_2})(\frac{\pi}{2}-\alpha)$ | $+1.5\times155.25\times.4724$ | 110.0100 | |
| $-\frac{e}{d}\cos\alpha\frac{1}{X_2}$ | $-1.5\times154.25\times.4705$ | | 108.8610 |
| $+\frac{r}{d}(1+\frac{1}{X_2})(1-\sin\alpha)$ | $3.125\times155.25-.1176$ | 57.0648 | |
| $\frac{r}{2dX_2}(1-\sin\alpha)$ | $-\frac{3.125\times154.25}{2}\times.1176$ | | 28.3434 |
| $-\frac{b}{d}\sin\alpha$ | $-1.25\times.8824$ | | 1.1030 |
| $-\frac{b}{d}$ | $-1.25$ | | 1.2500 |
| $+\sin\alpha$ | $+.8824$ | | .8824 |
| | | 226.5129 | 186.8404 |
| Coef of Q = | | 44.6725 | |

Substituting values just obtained.

$$-Ef\Delta b = 114.6933 \times M + 44.6725^{-} \Theta d$$

$$E = 28400000 \qquad f = .7854$$

$$\Delta b = \frac{114.6933 \times -.21797 + 44.6725}{28400000 \times .7854} \Theta d$$

$$= \frac{19.6736}{22305000} = .000000882034 \Theta d$$

Sample #2

Computations on Conveyor Link.
Four arcs and straight sides. Dia Ab

Value of M.

| Term | Substitution | Result |
|---|---|---|
| $+\frac{2}{K X_1}\sin\alpha$ | $\frac{2\times 13.93\times .8524}{1.5137}$ | 16.2376 |
| $+\left(\frac{1}{X_2}-\frac{1}{X_1}\right)\cos\alpha$ | $(15.425-13.93)\times .4705$ | 11.0158 |
| $-\frac{b}{d}\alpha\left(1+\frac{1}{X_1}\right)$ | $-1.25\times 1.0984\times 14.93$ | 20.4988 |
| $-\left(1+\frac{1}{X_2}\right)\left(\frac{\pi}{2}-\alpha\right)$ | $-155.25\times .4724$ | 73.3401 |
| | | 82.2534 93.8389 |
| | | 82.2534 |
| Numerator of M. | | -11.5855 |
| $+\alpha\left(1+\frac{1}{X_1}\right)$ | $+1.0984\times 14.93$ | 16.3991 |
| $+\frac{d}{r}\left(1+\frac{1}{X_2}\right)\left(\frac{\pi}{2}-\alpha\right)$ | $+\frac{155.25}{3.125}\times .4724$ | 23.4368 |
| $+16\frac{c}{d}$ | $+16\times 1.5$ | 24. |
| Denominator of M. | | 63.8359 |

$$M = \frac{-11.5855}{63.8359} = -.1814$$ Qd

## Coef of M

| Term | Substitution | Result | |
|---|---|---|---|
| $+\alpha\frac{e}{d}(1+\frac{1}{x_1})$ | $+1.0984 \times .1493$ | 16.3991 | |
| $+(1+\frac{1}{x_1})(\sin\alpha)$ | $+14.93 \times .8824$ | 13.1742 | |
| $+(1+\frac{1}{x_2})(1-\sin\alpha)$ | $+155.25 \times .1176$ | 18.2574 | |
| $-\sin\alpha$ | $-.8824$ | | .8824 |
| $-\frac{b}{r}$ | $-\frac{1.25}{3.125}$ | | .4 |
| $+\frac{d}{r}\sin\alpha$ | $+\frac{.8824}{3.125}$ | .2823 | |
| $+\frac{e}{r}(1+\frac{1}{x_2})(\frac{\pi}{2}-\alpha)$ | $+\frac{1.5}{3.125} \times 155.25 \times .4724$ | 35.3029 | |
| $+8\frac{e^2}{d^2}$ | $+8 \times 1.5 \times 1.5$ | 18. | |
| | | 101.4159 | 1.2824 |
| | | 1.2824 | |

Coef of M. = 100.1335

| | | | |
|---|---|---|---|
| $+\alpha\frac{bl}{d^2}(1+\frac{1}{x_1})$ | $+1.0984 \times 1.25 \times 14.93$ | 20.3864 | |
| $-\frac{l}{dx_1}(\frac{2\sin\alpha}{K}-\cos\alpha)$ | $-13.93(\frac{2 \times .8824}{1.5137}-.4705)$ | | 9.6841 |
| $+\frac{b}{dx_1}\sin\alpha$ | $+1.25 \times 13.93 \times .8824$ | 15.3978 | |
| $-\frac{1}{2x_1}\sin^2\alpha$ | $-\frac{13.93}{2} \times .8824^2$ | | 5.4240 |
| $-\frac{1}{4Kx_1}(2\sin^2\alpha+\sin\alpha\cos\alpha-\alpha)$ | $-\frac{13.93}{4 \times 1.5137}(2 \times .8824^2+.8824 \times .4705-1.0984)$ | | 2.2156 |
| $+\frac{r}{d}(1+\frac{1}{x_1})(1-\sin\alpha)$ | $3.125 \times 155.25 \times .1176$ | 57.0531 | |
| $-\frac{r}{2dx_2}\cos^2\alpha$ | $-\frac{3.125}{2} \times 154.25 \times .4705^2$ | | 53.6344 |
| $-\frac{b}{d}$ | $-1$ | | 1. |
| $+\sin\alpha$ | $+.8824$ | .8824 | |
| $+\frac{e}{d}(1+\frac{1}{x_2})(\frac{\pi}{2}-\alpha)$ | $+1.5 \times 155.25 \times .4724$ | 110.0100 | |
| $-\frac{e}{dx_2}\cos\alpha$ | $-1.5 \times 154.25 \times .4705$ | | 106.0392 |
| | | 203.1297 | 177.9973 |

Coef of Od 25.7324

Substituting

$$E = 28400000$$

$$f = .7854$$

$$-Efa\Delta b = (100.1335 \times -.1814 + 25.7324)\, Qd$$

$$-\Delta b = \frac{100.1335 \times -.1814 + 25.7324}{28400000 \times .7854}\, Qd$$

$$-\Delta b = \frac{7.5688}{22305000}\, Qd$$

$$= .0000003393\, Qd$$

Sample 5

Six arc analysis.
Computations on Bridge Link. Dis 4b.

Using values as follows, same being shown on sketch of sample.

$\alpha = 19°30' = .34$
$\sin\alpha = .3338$
$\cos\alpha = .9426$
$\beta = 77°30' = 1.353$
$\sin\beta = .9763$
$\cos\beta = .2164$
$r_2 = 1.2$
$r_3 = 5.$

$d = 1.$
$c = 1.16$
$h = 1.26$
$a = 1.875$
$b = 1.1875$
$\frac{1}{r_1} = 13.93$
$\frac{1}{r_2} = 21.$
$\frac{1}{r_3} = 398$

$K = .6546$

Computations give $M = -.3668\,Qd$

and $-Ef\Delta b = 45.3110\,M + 20.5166\,Qd$
$= 4.776\,Qd$

Now $E = 24600,000$
$f = .7854$

$$\Delta b = \frac{4.776\ Qd}{24600000 \times .7854} = .000000247\ Qd$$

# VI Summary & Conclusions.

The computations being long and complicated, only a few were made, because of the limited time. The first was made on the dredge chain, sample #5.

Assuming distributed load and center-line of four circular arcs. This clearly showed that the four arc assumption gave too large an area of contact. Computations on sb of the Conveyor link sample #2 also showed the same thing. Hence six circular arcs were substituted for the center-line, & being made of such a size as to include only the surface of contact. Calculations on this basis, as plotted on curve sheet of sample #5, give a close agreement with the experiments.

From the calculated deformations, on sample #2, shown on the curve sheet, It appears that the actual deformations lie between the calculated deformations for concentrated and distributed loads.

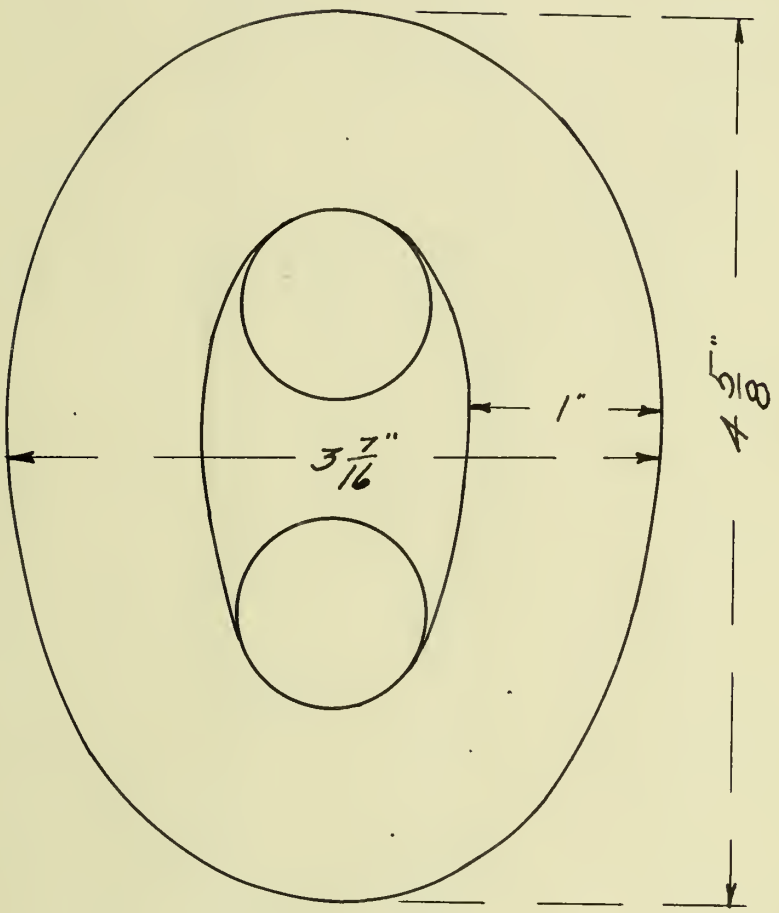
Hence it may be argued that the actual condition of loading lies between

the two assumptions, viz: concentration, and distribution according to the cosine law with four circular arc center-line.

And further it seems probable that after further adjustment the six circular arc center-line, and distribution according to cosine law will fully agree with actual results.

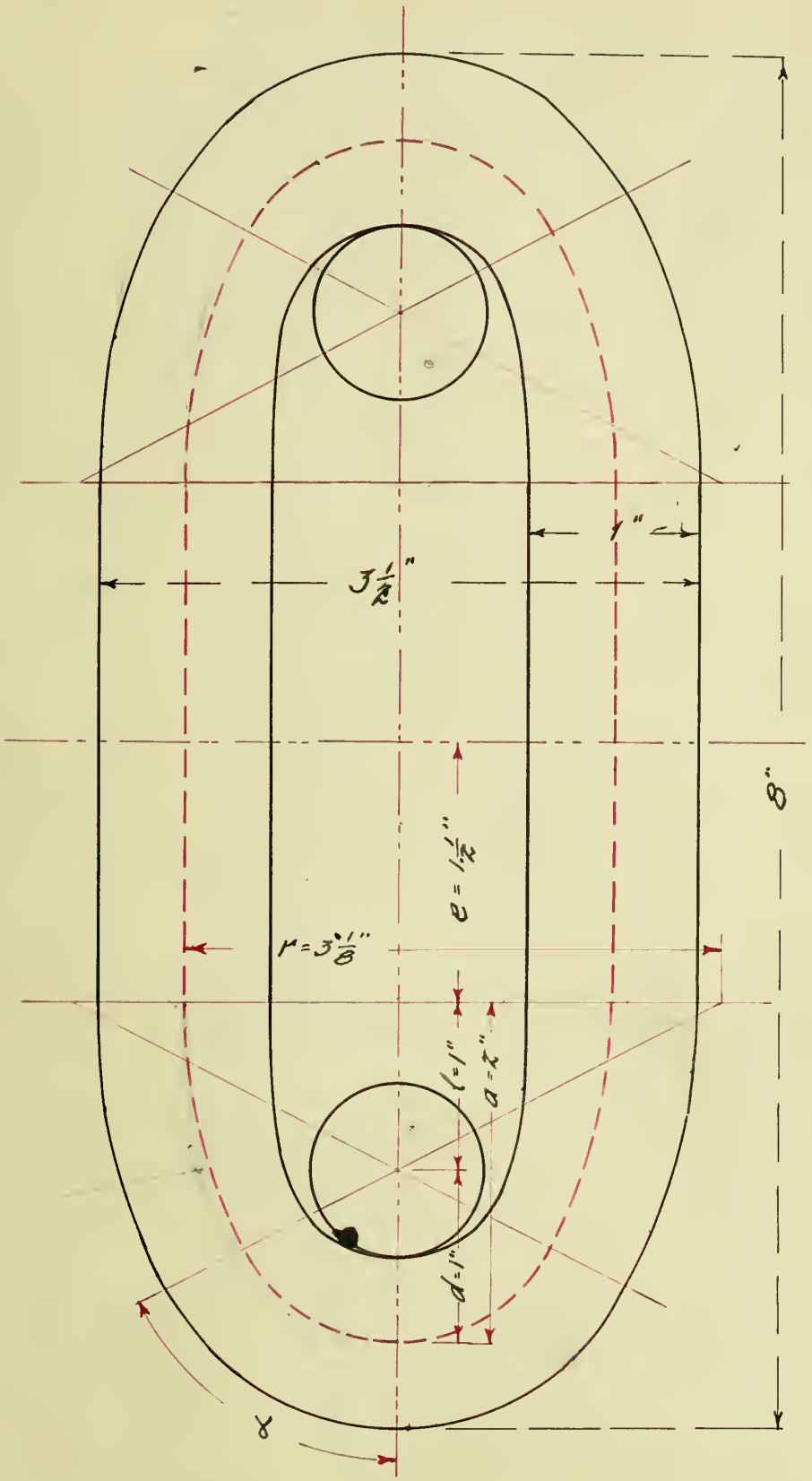
# VII Data of Lists and Comparative Curve Shunts

Sample 1



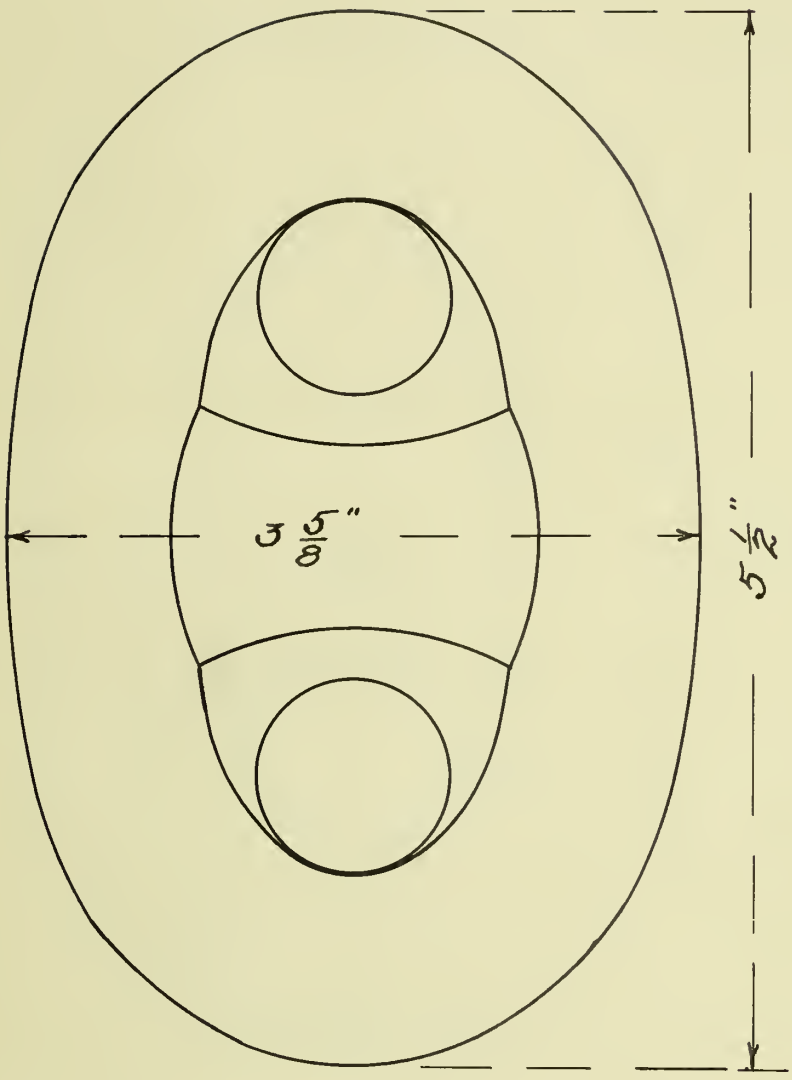

N.I.C.&F. Co. Dredge Chain.

Sample 2



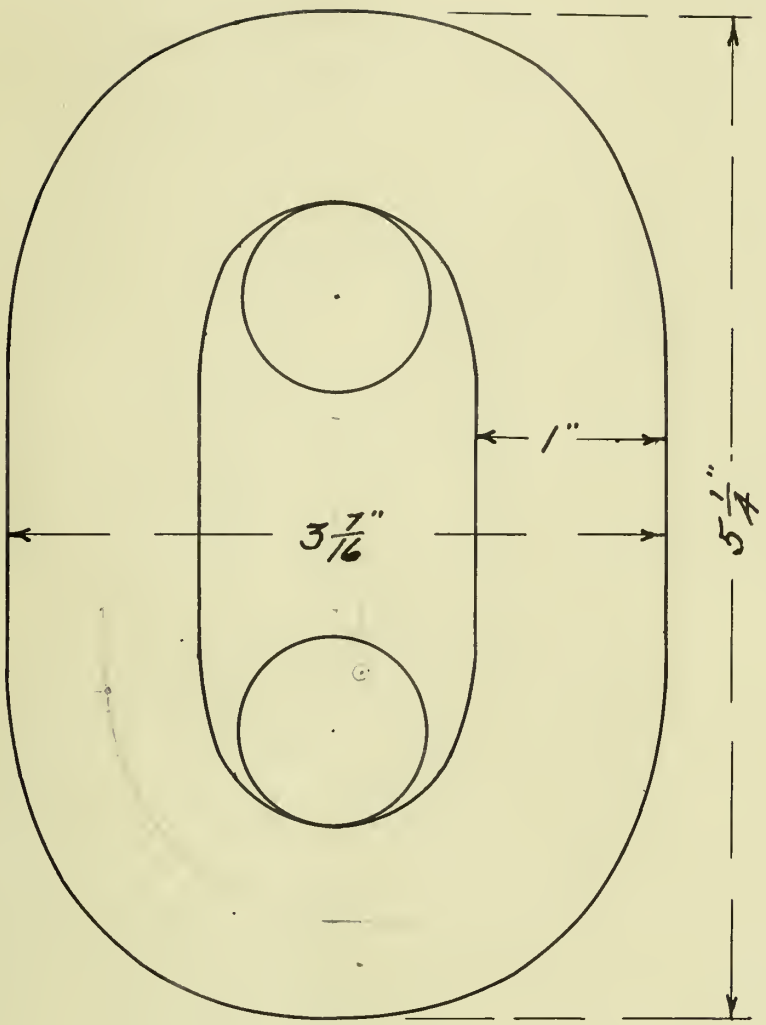

N.I.C. & F. Co. Conveyor Chain.

Sample 3



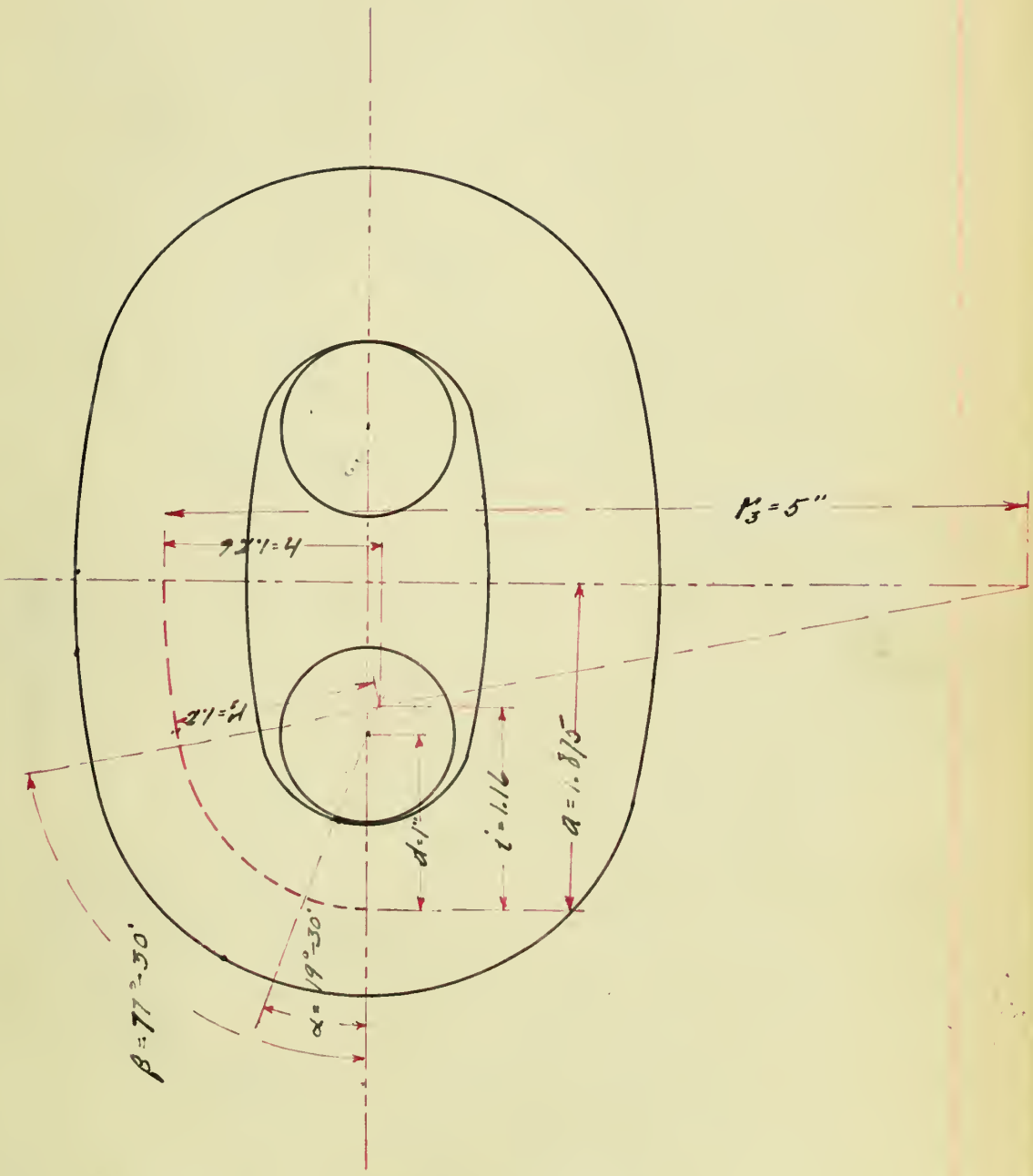

N.I.C.&F. Co. Stud Chain.

Sample A



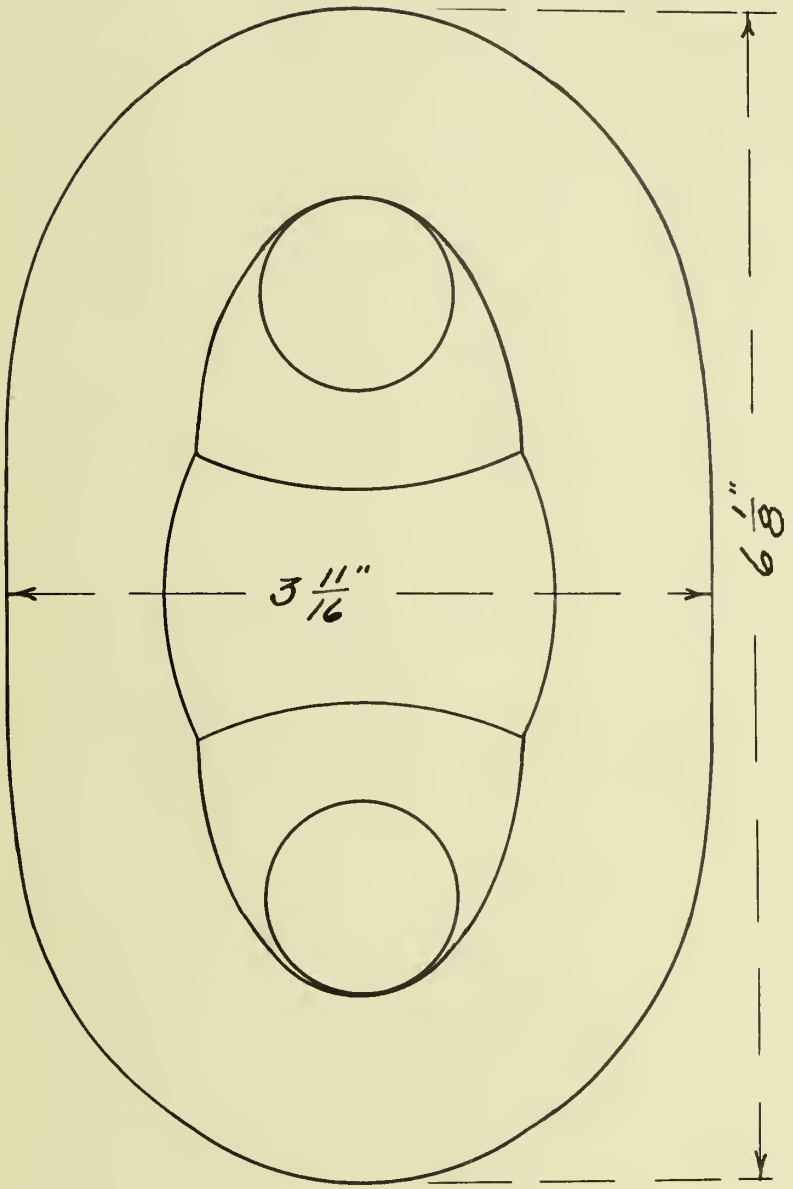

J. L. & Co Proof Coil Chain.

Sample 5




J.L. & Co. Dredge Chain.

Sample 6




J. L. & Co. Stud Chain.

TEST #1 SAMPLE #1

# SENECA SPECIAL IRON

| Load | Readings | | Differences | | Aver. |
|---|---|---|---|---|---|
| 1510 | .0622 | .1031 | — | — | — |
| 2680 | .0625 | .1034 | .0003 | .0003 | .0003 |
| 5060 | .0625 | .1050 | .0003 | .0019 | .0011 |
| 7500 | .0626 | .1065 | .0004 | .0034 | .0019 |
| 10000 | .0625 | .1082 | .0003 | .0051 | .0027 |
| 12500 | .0626 | .1097 | .0004 | .0066 | .0035 |
| 15000 | .0631 | .1109 | .0009 | .0078 | .00435 |
| 17500 | .0637 | .1117 | .0015 | .0086 | .00505 |
| 20000 | .0661 | .1108 | .0039 | .0077 | .0058 |
| 22500 | .0719 | .1065 | .0097 | .0034 | .00655 |
| 25000 | .0743 | .1054 | .0121 | .0023 | .0072 |
| 26500 | Elastic limit. | | | | |
| 27500 | .2484 | .2564 | .1862 | .1533 | .16975 |

Diam — 1.036"
Link — Dredge
E. — 29200000
Elastic Limit — 26500#
Max. Load. — 40600#
Elongation — 22.7%

TEST #2 SAMPLE #2.

## COMMON IRON

| Load | Readings | | Difference | | Aver |
|---|---|---|---|---|---|
| 1000 | .0562 | .1057 | —— | —— | —— |
| 2500 | .0554 | .1076 | -.0008 | .0019 | .00055 |
| 5100 | .0553 | .1093 | -.0009 | .0036 | .00135 |
| 7500 | .0538 | .1124 | -.0024 | .0067 | .00215 |
| 10000 | .0528 | .1148 | -.0034 | .0091 | .00285 |
| 12500 | .0524 | .1169 | -.0038 | .0112 | .0037 |
| 15000 | .0522 | .1191 | -.0040 | .0134 | .0047 |
| 17500 | .0530 | .1197 | -.0032 | .0140 | .0054 |
| 20000 | .0548 | .1197 | -.0014 | .0140 | .0063 |
| 22500 | .0572 | .1189 | .0010 | .0132 | .0071 |
| 25000 | .0598 | .1182 | .0036 | .0125 | .00805 |
| 27500 | .2244 | .2714 | .1682 | .1657 | .16675 |

Diam - 1.035"
Link - Conveyor
E. - 28400000
Elastic Limit - 25000#
Max. Load - 40615#
Elongation

TEST #3 SAMPLE #3

# B.B. IRON

| Load | Readings | | Difference | | Aver. |
|---|---|---|---|---|---|
| 1000 | .0506 | .1120 | ——— | ——— | ——— |
| 5000 | .0474 | .1182 | -.0032 | .0062 | .0017 |
| 10000 | .0478 | .1212 | -.0028 | .0092 | .0032 |
| 12500 | .0482 | .1225 | -.0024 | .0105 | .00405 |
| 15000 | .0487 | .1234 | -.0019 | .0114 | .00475 |
| 17500 | .0495 | .1244 | -.0011 | .0124 | .00565 |
| 20000 | .0519 | .1235 | .0013 | .0015 | .0014 |
| 22500 | .0565 | .1202 | .0059 | .0082 | .00705 |
| 25000 | .0643 | .1145 | .0137 | .0025 | .00810 |
| 27500 | .0669 | .1131 | .0163 | .0011 | .0087 |
| 28000 | Elastic Limit | | | | |

Diam — 1.037"
Link — Stud
E. — 29500000
Elastic Limit — 28000#
Max. Load — 42300#
Elongation — 23.8%

SENECA SPECIAL

Nº 1 Diam 1.036"

Link Dredge

E 29200000

Max. Load 40600#

Elongation 22.7%

Elastic Limit 26500#

COMMON IRON

Nº 2 Diam 1.035"

Link Conveyor

E 28400000

Max. Load 40615#

Elongation

Elastic Limit 25000#

B. B. IRON

Nº 3 Diam 1.037"

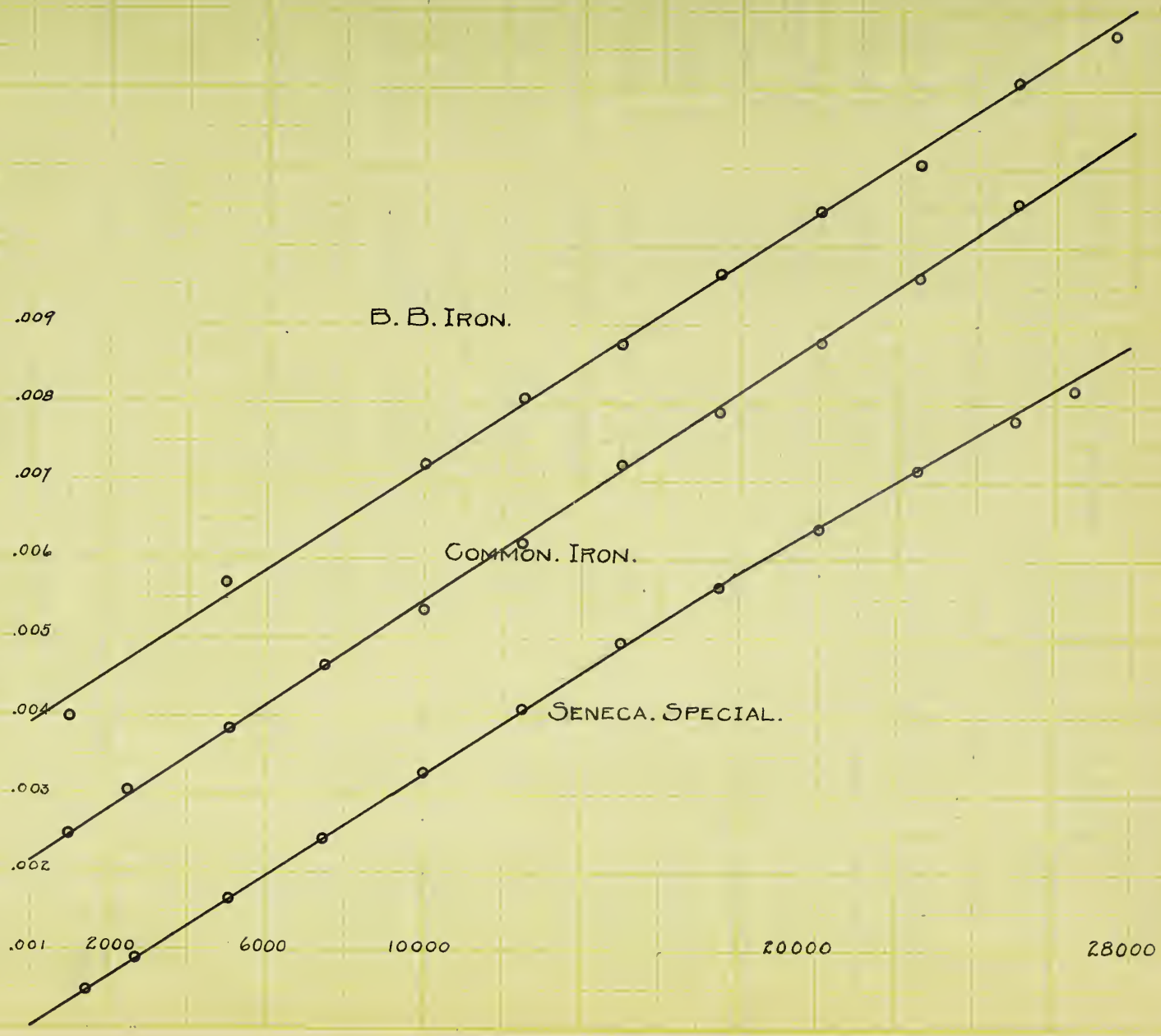
Link Stud

E 29500000

Max Load 42300#

Elongation 23.8%

Elastic Limit 28000#



TEST #10 SAMPLE #4

STEEL — PROOF COIL CHAIN

| Load | Readings | | Difference | | Aver. |
|---|---|---|---|---|---|
| 515 | .2417 | .2344 | — | — | — |
| 2250 | .2457 | .2317 | .0040 | -.0027 | .0065 |
| 4025 | .2467 | .2320 | .0050 | -.0024 | .0013 |
| 6200 | .2467 | .2335 | .0050 | -.0009 | .00205 |
| 7800 | .2469 | .2344 | .0052 | .0000 | .00260 |
| 9900 | .2470 | .2356 | .0053 | .0012 | .00345 |
| 11920 | .2472 | .2368 | .0053 | .0024 | .00395 |
| 13800 | .2470 | .2385 | .0053 | .0041 | .00470 |
| 14700 | .2467 | .2399 | .0050 | .0055 | .00525 |
| 17590 | .2463 | .2444 | .0046 | .0100 | .0073 |
| 19560 | .2484 | .2548 | .0067 | .0204 | .01355 |
| 21940 | .2761 | .2779 | .0344 | .0435 | .03895 |
| 24000 | .3305 | .3310 | .0888 | .0966 | .09270 |

Diam — 1.035

Link — Proof Coil.

E. — 26100000

Elastic Limit — 16200 #

Max. Load — 42550 #

Elongation — 32 %

TEST #11 SAMPLE #5.

IRON

| Load | Readings | | Differences | | Aver. |
|---|---|---|---|---|---|
| 250 | .2440 | .2349 | — | — | — |
| 2000 | .2459 | .2333 | .0019 | .0016 | .00015 |
| 4000 | .2476 | .2332 | .0036 | .0017 | .00095 |
| 6000 | .2488 | .2337 | .0048 | .0012 | .00180 |
| 8000 | .2499 | .2344 | .0059 | .0005 | .00270 |
| 10,000 | .2509 | .2351 | .0069 | .0002 | .00355 |
| 12000 | .2517 | .2359 | .0077 | .0010 | .00435 |
| 14000 | .2524 | .2368 | .0084 | .0019 | .00515 |
| 16000 | .2532 | .2376 | .0092 | .0027 | .00595 |
| 18000 | .2541 | .2388 | .0101 | .0039 | .0070 |
| 20000 | .2546 | .2404 | .0106 | .0055 | .00805 |
| 22000 | .2541 | .2428 | .0101 | .0079 | .0090 |
| 24000 | .2524 | .2465 | .0084 | .0116 | .0100 |

Diam — .997
Link — Dredge
E. — 24600000
Elastic Limit — 25000#
Max. Load — 37680#
Elongation. — 26 %

TEST #12 SAMPLE #6

IRON

| Load | Readings | | Differences | | Aver. |
|---|---|---|---|---|---|
| 640 | .2388 | .2334 | —— | —— | —— |
| 3000 | .2404 | .2334 | .0016 | .0000 | .0008 |
| 5000 | .2421 | .2333 | .0033 | .0001 | .0016 |
| 7000 | .2432 | .2337 | .0044 | .0003 | .00235 |
| 9000 | .2446 | .2338 | .0058 | .0004 | .00310 |
| 11000 | .2462 | .2337 | .0074 | .0003 | .00385 |
| 13000 | .2469 | .2343 | .0081 | .0009 | .00450 |
| 15000 | .2478 | .2347 | .0090 | .0013 | .00515 |
| 17000 | .2488 | .2352 | .0100 | .0018 | .00590 |
| 19000 | .2497 | .2358 | .0109 | .0024 | .00665 |
| 21000 | .2503 | .2368 | .0115 | .0034 | .00745 |
| 23000 | .2464 | .2414 | .0076 | .0080 | .00780 |
| 24000 | .2468 | .2421 | .0080 | .0087 | .00835 |
| 25700 | .4379 | .4380 | .1991 | .2046 | .20185 |

Diam — 1.000
Link — Stud
E. — 26000000
Elastic Limit — 24700
Max. Load — 35660#
Elongation — 16 %

STEEL

No 4 Diam 1.035

Link Proof Coil

E. 26100000

Max. Load 42550#

Elongation 32 %

Elastic Limit 16200#

IRON

No 5 Diam .997

Link Dredge

E 24600000

Max. Load 37680#

Elongation 26 %

Elastic Limit 25000#

IRON

No 6 Diam 1.000

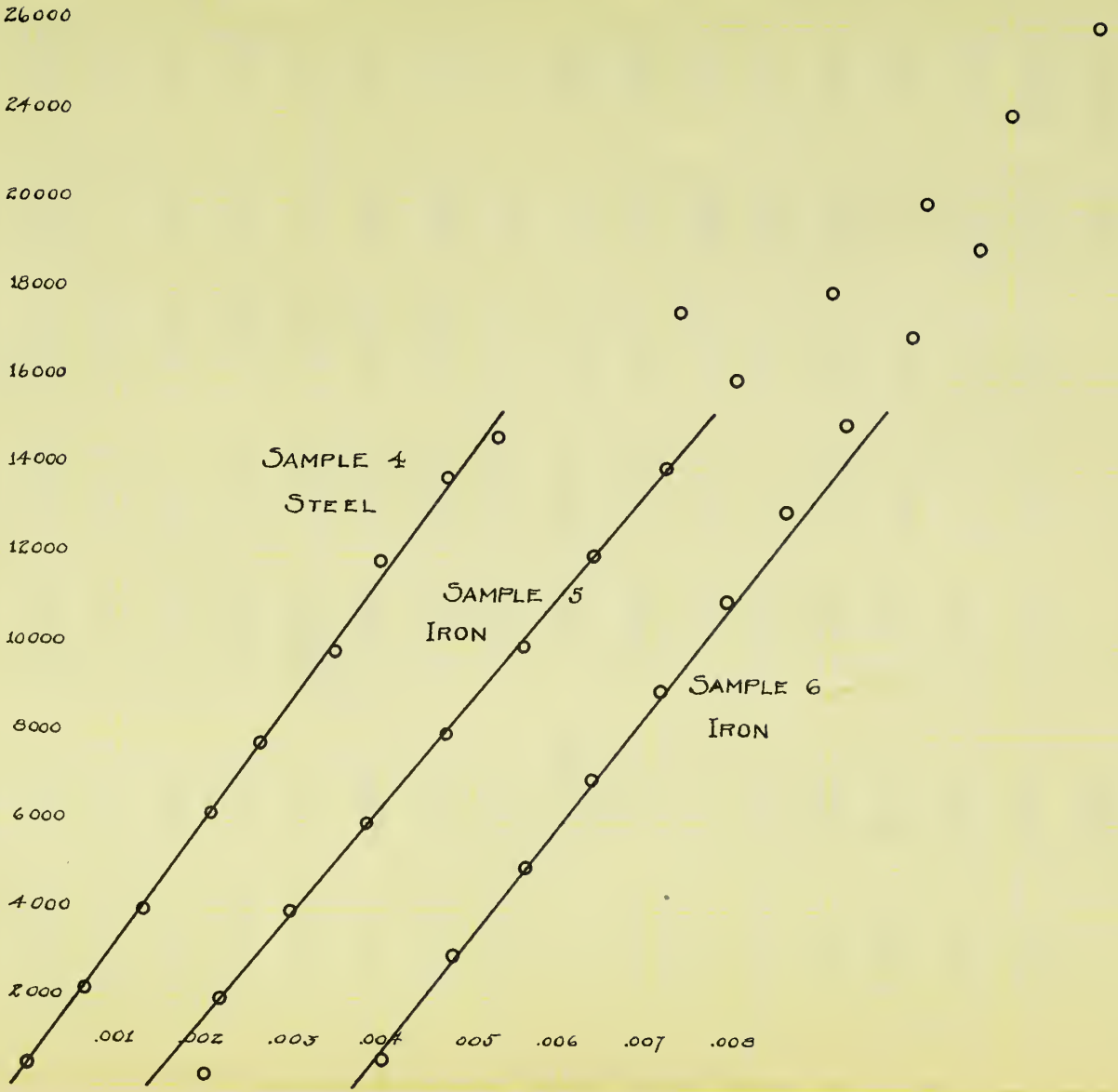
Link Stud

E 26000000

Max. Load 35660

Elongation 16 %

Elastic Limit 24700#



TEST #8 SAMPLE #1

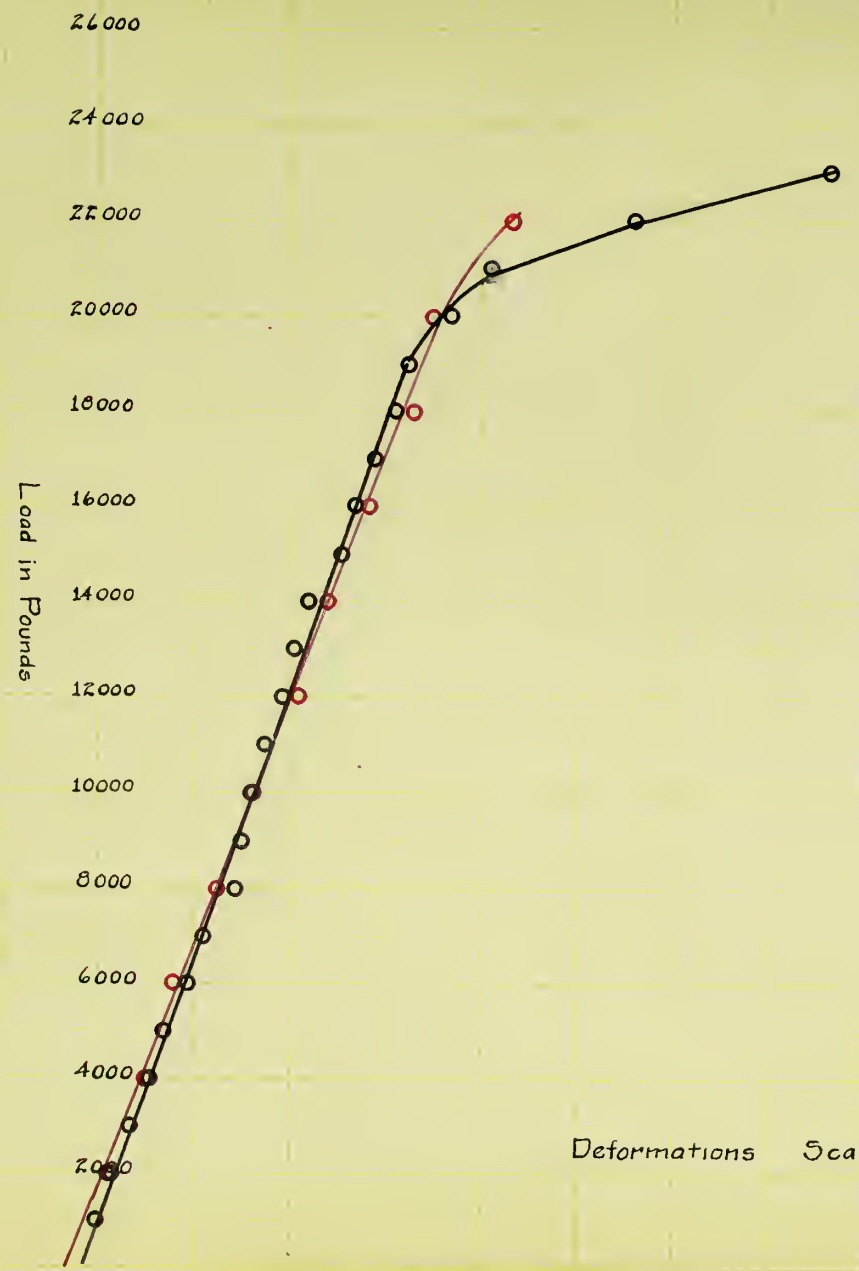
# DREDGE CHAIN

| Load | Readings | | Difference | | Aver | Read. | Diff. |
|---|---|---|---|---|---|---|---|
| 1000 | .0058 | .0079 | — | — | — | .4098 | — |
| 2000 | .0059 | .0080 | .0001 | .0001 | .0001 | .4097 | .0001 |
| 3000 | .0061 | .0083 | .0003 | .0004 | .00035 | .4092 | .0006 |
| 4000 | .0061 | .0087 | .0003 | .0008 | .00055 | .4089 | .0009 |
| 5000 | .0062 | .0089 | .0004 | .0010 | .0007 | .4087 | .0011 |
| 6000 | .0064 | .0092 | .0006 | .0013 | .00095 | .4085 | .0013 |
| 7000 | .0066 | .0093 | .0008 | .0014 | .0011 | .4084 | .0014 |
| 8000 | .0065 | .0101 | .0007 | .0022 | .00145 | .4081 | .0017 |
| 9000 | .0066 | .0101 | .0008 | .0022 | .0015 | .4080 | .0018 |
| 10000 | .0066 | .0103 | .0008 | .0024 | .0016 | .4079 | .0019 |
| 11000 | .0068 | .0104 | .0010 | .0025 | .00175 | .4077 | .0021 |
| 12000 | .0068 | .0108 | .0010 | .0029 | .00195 | .4074 | .0024 |
| 13000 | .0068 | .0110 | .0010 | .0031 | .00205 | .4073 | .0025 |
| 14000 | .0069 | .0112 | .0011 | .0033 | .0022 | .4070 | .0028 |
| 15000 | .0070 | .0118 | .0012 | .0039 | .00255 | .4070 | .0028 |
| 16000 | .0072 | .0119 | .0014 | .0040 | .0027 | .4069 | .0029 |
| 17000 | .0075 | .0120 | .0017 | .0041 | .0029 | .4068 | .0030 |
| 18000 | .0076 | .0123 | .0018 | .0044 | .0031 | .4062 | .0036 |
| 19000 | .0076 | .0126 | .0018 | .0047 | .00325 | .4062 | .0036 |
| 20000 | .0077 | .0134 | .0019 | .0055 | .0037 | .4056 | .0042 |
| 21000 | .0075 | .0144 | .0017 | .0065 | .0041 | .4050 | .0048 |
| 22000 | .0069 | .0180 | .0011 | .0101 | .0056 | .4043 | .0055 |
| 23000 | .0071 | .0219 | .0013 | .0140 | .00765 | .4042 | .0076 |

CHECK on TEST #8 SAMPLE #1

# DREDGE CHAIN

| Load | Readings | | Difference | | Aver. | Read. Diff. | |
|---|---|---|---|---|---|---|---|
| 1000 | .0194 | .0060 | — | — | — | .1887 | — |
| 2000 | .0195 | .0062 | .0001 | .0002 | .00015 | .1885 | .0002 |
| 4000 | .0196 | .0068 | .0002 | .0008 | .0005 | .1881 | .0006 |
| 6000 | .0199 | .0071 | .0005 | .0011 | .0008 | .188 | .0011 |
| 8000 | .0202 | .0077 | .0008 | .0017 | .00125 | 1812 | .0015 |
| 10000 | .0203 | .0084 | .0009 | .0024 | .00165 | .1870 | .0017 |
| 12000 | .0206 | .0090 | .0012 | .0030 | .0021 | .1876 | .0021 |
| 14000 | .0209 | .0093 | .0015 | .0033 | .0024 | .1863 | .0024 |
| 16000 | .0211 | .0100 | .0017 | .0040 | .00285 | .1857 | .0030 |
| 18000 | .0216 | .0104 | .0022 | .0044 | .0033 | .1854 | .0033 |
| 20000 | .0217 | .0108 | .0023 | .0048 | .0035 | .1853 | .0034 |
| 22000 | .0224 | .0117 | .0030 | .0057 | .00435 | .1849 | .0038 |




TEST 8 SAMPLE 1

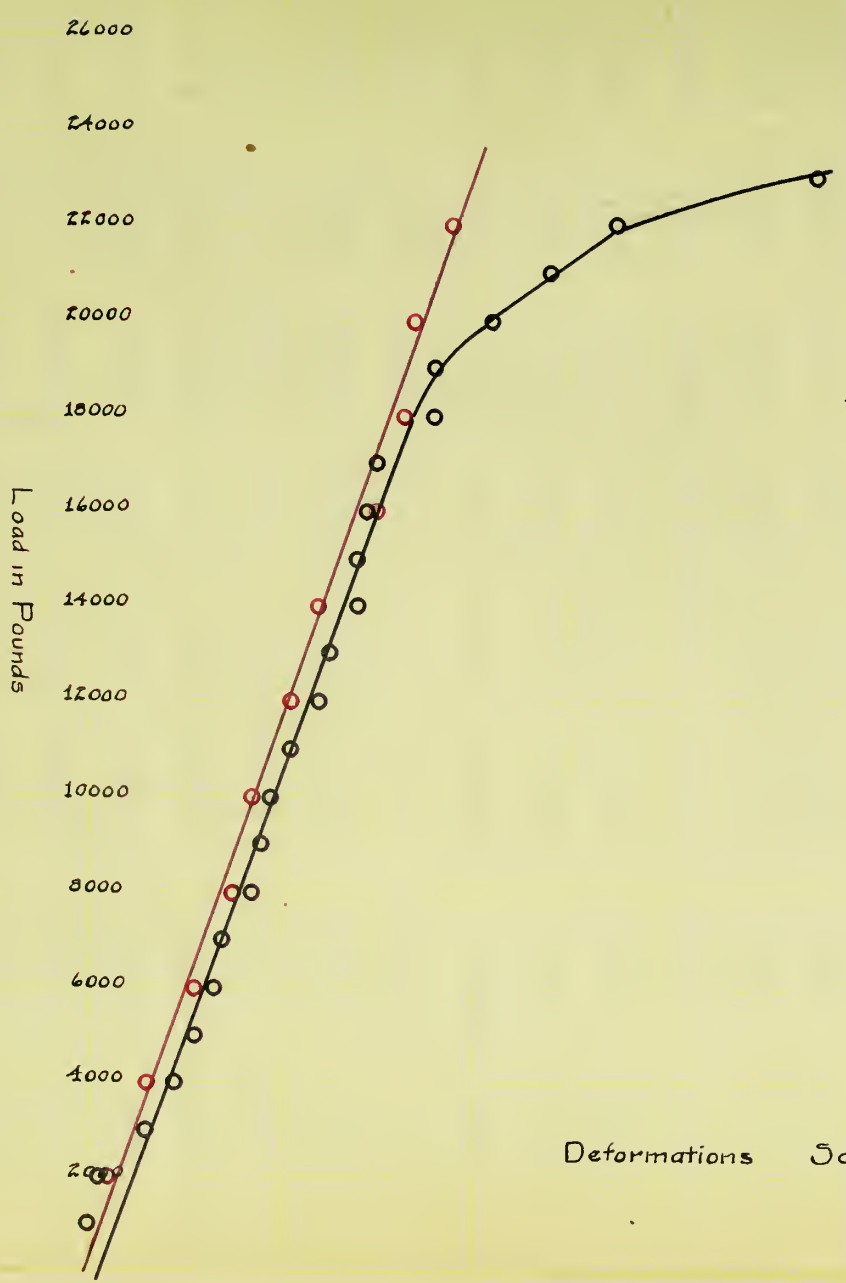
DREDGE CHAIN

Deformations of Major Axis

First Test o Check Test o

Theoretical Deformations

Journal Contact — Line Contact —




TEST 8 SAMPLE 1

DREDGE CHAIN

Deformations of Minor Axis

First Test o Check Test o

Theoretical Deformations

Journal Contact — Line Contact —

Deformations Scale $\frac{1}{2}$" = .001

TEST #4 SAMPLE #2

CONVEYOR CHAIN

| Load# | Readings" | Difference" | Aver." | | | Read." | Diff." |
|---|---|---|---|---|---|---|---|
| 1500 | .1363 | .0400 | — | — | — | .4875 | — |
| 2000 | .1368 | .0399 | .0005 | .0001 | .0002 | .4880 | .0005 |
| 2500 | .1371 | .0407 | .0008 | .0007 | .00075 | .4870 | .0005 |
| 3000 | .1383 | .0401 | .0020 | .0001 | .00105 | .4869 | .0006 |
| 3500 | .1389 | .0401 | .0026 | .0001 | .00135 | .4865 | .0010 |
| 4000 | .1390 | .0404 | .0027 | .0004 | .00155 | .4863 | .0012 |
| 4500 | .1395 | .0407 | .0032 | .0007 | .00195 | .4860 | .0015 |
| 5000 | .1398 | .0408 | .0035 | .0008 | .00215 | .4860 | .0015 |
| 5500 | .1401 | .0409 | .0038 | .0009 | .00235 | .4855 | .0020 |
| 6000 | .1401 | .0416 | .0038 | .0016 | .0027 | .4853 | .0022 |
| 6500 | .1404 | .0410 | .0041 | .0010 | .00255 | .4850 | .0025 |
| 7000 | .1405 | .0412 | .0042 | .0012 | .0027 | .4847 | .0028 |
| 7500 | .1408 | .0413 | .0045 | .0013 | .0029 | .4843 | .0032 |
| 8000 | .1410 | .0417 | .0047 | .0017 | .0032 | .4840 | .0038 |
| 8500 | .1411 | .0418 | .0048 | .0018 | .0033 | .4837 | .0038 |
| 9000 | .1413 | .0419 | .0050 | .0019 | .00345 | .4834 | .0041 |
| 9000 | .1408 | .0422 | — | — | — | .4832 | — |
| 10000 | .1420 | .0425 | .0062 | .0022 | .0042 | .4830 | .0043 |
| 11000 | .1425 | .0429 | .0067 | .0026 | .00465 | .4822 | .0053 |
| 12000 | .1427 | .0430 | .0069 | .0027 | .0048 | .4814 | .0061 |
| 13000 | .1432 | .0436 | .0074 | .0033 | .00535 | .4810 | .0065 |
| 14000 | .1434 | .0443 | .0076 | .0040 | .00580 | .4800 | .0075 |
| 15000 | .1437 | .0448 | .0079 | .0045 | .00620 | .4791 | .0084 |

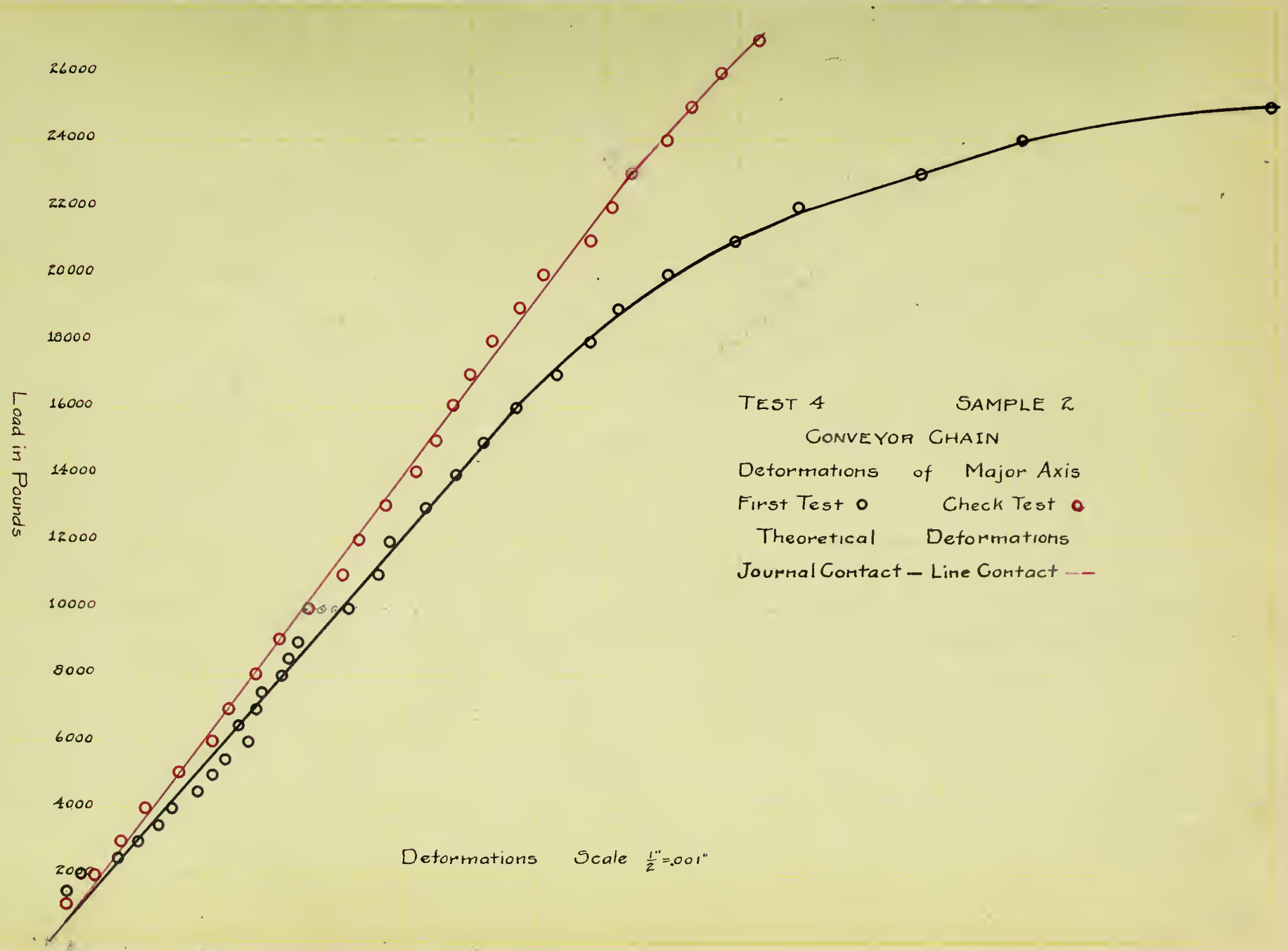
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 16000 | .1443 | .0452 | .0085 | .0049 | .0067 | .4782 | .0093 |
| 17000 | .1448 | .0459 | .0090 | .0056 | .0073 | .4774 | .0101 |
| 18000 | .1458 | .0459 | .0100 | .0056 | .0078 | .4766 | .0109 |
| 19000 | .1462 | .0463 | .0104 | .0060 | .0082 | .4754 | .0121 |
| 20000 | .1470 | .0470 | .0112 | .0067 | .00895 | .4740 | .0135 |
| 21000 | .1485 | .0474 | .0127 | .0071 | .0099 | .4724 | .0151 |
| 22000 | .1499 | .0480 | .0141 | .0077 | .0109 | .4710 | .0165 |
| 23000 | .1517 | .0498 | .0159 | .0095 | .0127 | | |
| 24000 | .1533 | .0512 | .0175 | .0109 | .0142 | .4660 | .0215 |
| 25000 | .1569 | .0551 | .0211 | .0148 | .01795 | .4620 | .0255 |

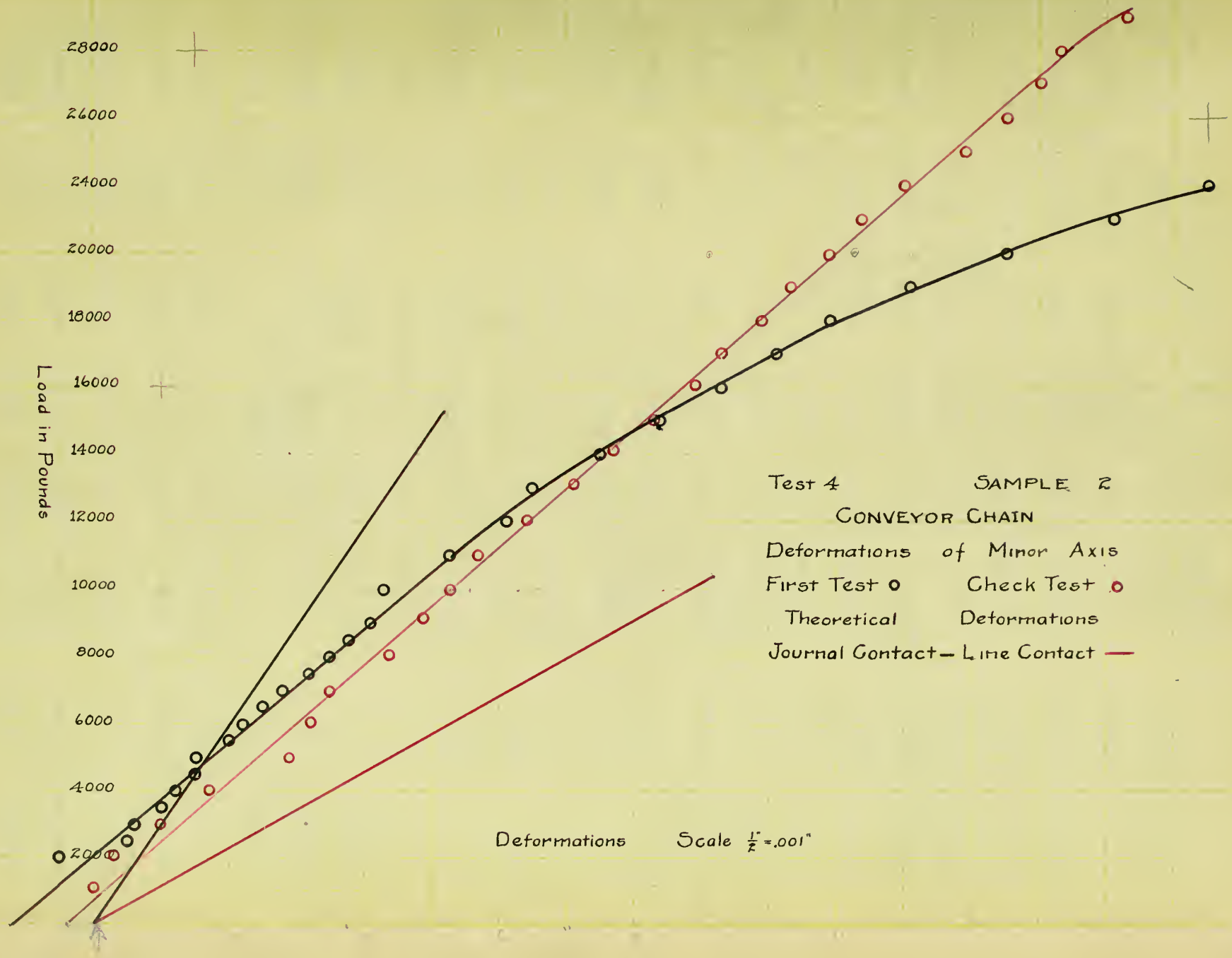
CHECK on TEST #4 SAMPLE #2

# CONVEYOR CHAIN

| Load # | Readings | Difference | Aver." | | | Read. Diff." | |
|---|---|---|---|---|---|---|---|
| 1120 | .1835 | .0292 | — | — | — | .4013 | — |
| 2040 | .1840 | .0295 | .0005 | .0003 | .0004 | .4010 | .0003 |
| 3020 | .1843 | .0300 | .0008 | .0008 | .0008 | .4003 | .0010 |
| 4000 | .1848 | .0302 | .0013 | .0010 | .00115 | .3996 | .0017 |
| 5110 | .1852 | .0308 | .0017 | .0016 | .00165 | .3984 | .0029 |
| 6040 | .1858 | .0312 | .0023 | .0020 | .00215 | .3981 | .0032 |
| 7000 | .1860 | .0315 | .0025 | .0023 | .0024 | .3978 | .0035 |
| 8030 | .1864 | .0319 | .0029 | .0027 | .0028 | .3969 | .0044 |
| 9190 | .1867 | .0323 | .0032 | .0031 | .00315 | .3964 | .0049 |
| 10000 | .1873 | .0326 | .0038 | .0034 | .0036 | .3960 | .0053 |
| 11000 | .1880 | .0329 | .0045 | .0037 | .0041 | .3956 | .0057 |
| 12020 | .1882 | .0332 | .0047 | .0040 | .00435 | .3949 | .0064 |
| 13090 | .1886 | .0336 | .0051 | .0044 | .00475 | .3942 | .0071 |
| 14090 | .1890 | .0341 | .0055 | .0049 | .0052 | .3936 | .0077 |
| 15030 | .1892 | .0345 | .0057 | .0053 | .0055 | .3930 | .0083 |
| 16090 | .1895 | .0347 | .0060 | .0055 | .00575 | .3924 | .0089 |
| 17020 | .1897 | .0350 | .0062 | .0058 | .0060 | .3920 | .0093 |
| 18000 | .1898 | .0356 | .0063 | .0064 | .00635 | .3914 | .0099 |
| 19000 | .1907 | .0355 | .0072 | .0063 | .00675 | .3910 | .0103 |
| 20000 | .1910 | .0359 | .0075 | .0067 | .0071 | .3904 | .0109 |
| 21000 | .1918 | .0365 | .0083 | .0073 | .0078 | .3899 | .0114 |
| 22000 | .1922 | .0367 | .0087 | .0075 | .0081 | .3893 | .0120 |
| 23000 | .1923 | .0372 | .0088 | .0080 | .0084 | .3884 | .0129 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 24000 | .1928 | .0378 | .0093 | .0086 | .00895 | .3878 | .0135 |
| 25000 | .1933 | .0380 | .0098 | .0088 | .0093 | .3873 | .0140 |
| 26000 | .1940 | .0382 | .0105 | .0090 | .00975 | .3870 | .0143 |
| 27000 | .1944 | .0389 | .0109 | .0097 | .0103 | .3860 | .0153 |
| 28000 | .2081 | .0542 | .0246 | .0270 | .0258 | | |
| 29000 | .2185 | .0673 | .0350 | .0381 | .03655 | | |


26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
Load in Pounds
TEST 4 SAMPLE 2
CONVEYOR CHAIN
Deformations of Major Axis
First Test o Check Test o
Theoretical Deformations
Journal Contact — Line Contact – –
Deformations Scale 1/2" = .001"


28000
26000
24000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
Load in Pounds
Test 4 SAMPLE 2
CONVEYOR CHAIN
Deformations of Minor Axis
First Test o Check Test o
Theoretical Deformations
Journal Contact — Line Contact —
Deformations Scale 1" = .001"

TEST #5 SAMPLE #3

# STUD LINK CHAIN

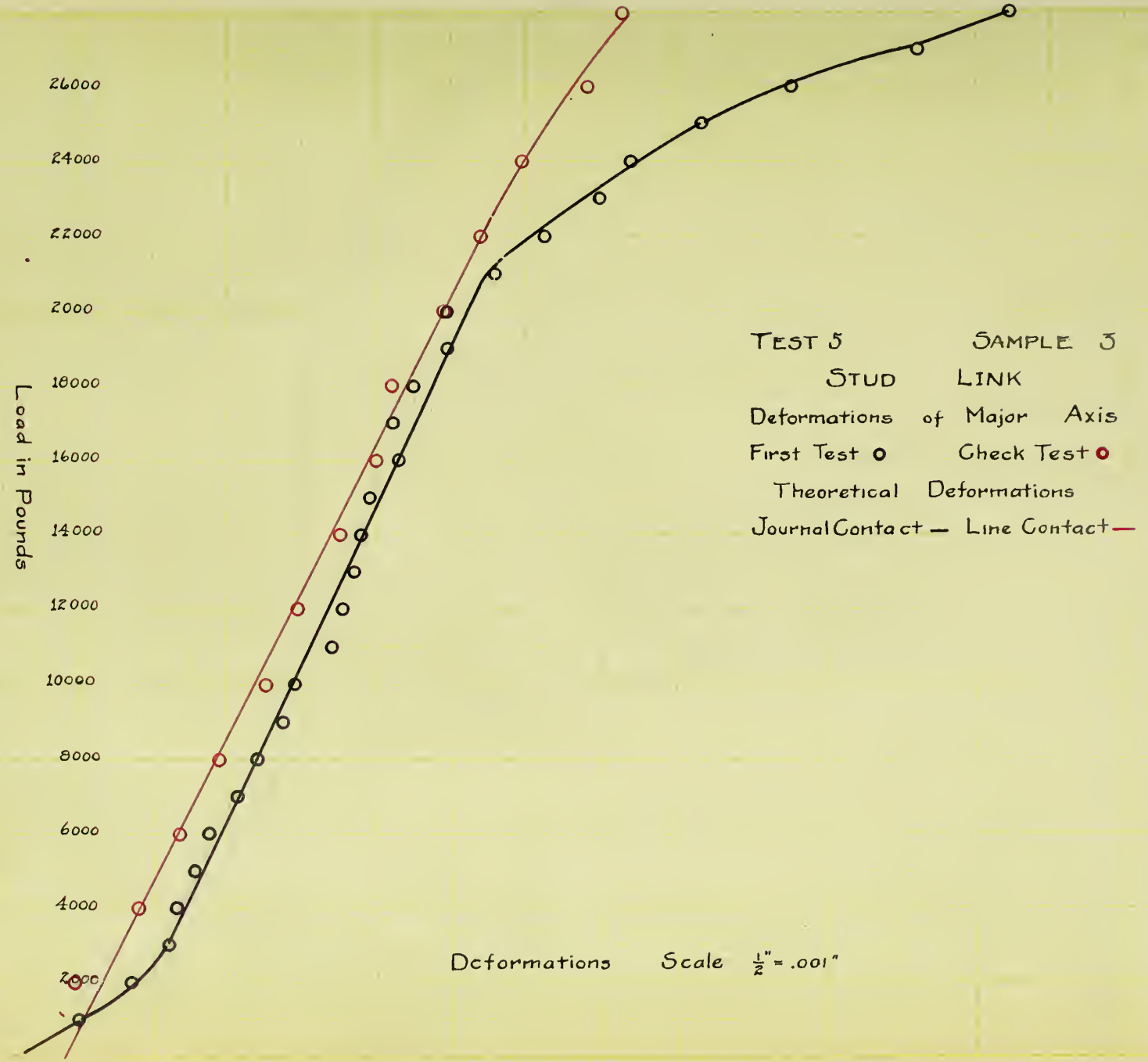
| Load | Readings | | Difference | | Aver | Read. | Diff. |
|---|---|---|---|---|---|---|---|
| 1000 | .0660 | .0357 | — | — | — | .4610 | — |
| 2000 | .0680 | .0363 | .0008 | .0006 | .0007 | .4600 | .0010 |
| 3000 | .0675 | .0366 | .0015 | .0009 | .0012 | .4598 | .0012 |
| 4000 | .0676 | .0367 | .0016 | .0010 | .0013 | .4595 | .0015 |
| 5000 | .0679 | .0369 | .0019 | .0012 | .00155 | .4594 | .0016 |
| 6000 | .0682 | .0370 | .0022 | .0013 | .00175 | .4589 | .0021 |
| 7000 | .0688 | .0371 | .0028 | .0014 | .0021 | .4581 | .0029 |
| 8000 | .0689 | .0376 | .0029 | .0019 | .0024 | .4581 | .0029 |
| 9000 | .0694 | .0378 | .0034 | .0021 | .00275 | .4580 | .0030 |
| 10000 | .0697 | .0378 | .0037 | .0021 | .0029 | .4582 | .0028 |
| 11000 | .0704 | .0381 | .0044 | .0024 | .0034 | .4581 | .0029 |
| 12000 | .0706 | .0382 | .0046 | .0025 | .00355 | .4582 | .0028 |
| 13000 | .0709 | .0382 | .0049 | .0025 | .0037 | .4583 | .0027 |
| 14000 | .0710 | .0383 | .0050 | .0026 | .0038 | .4580 | .0030 |
| 15000 | .0715 | .0380 | .0055 | .0023 | .0039 | .4580 | .0030 |
| 16000 | .0719 | .0384 | .0059 | .0027 | .0043 | .4580 | .0030 |
| 17000 | .0720 | .0381 | .0060 | .0024 | .0042 | .4580 | .0030 |
| 18000 | .0723 | .0384 | .0063 | .0027 | .0045 | .4580 | .0030 |
| 19000 | .0730 | .0386 | .0070 | .0029 | .00495 | .4578 | .0032 |
| 20000 | .0729 | .0387 | .0069 | .0030 | .00495 | .4574 | .0036 |
| 21000 | .0736 | .0393 | .0076 | .0036 | .0056 | .4571 | .0039 |
| 22000 | .0742 | .0400 | .0082 | .0043 | .00625 | .4572 | .0038 |
| 23000 | .0750 | .0407 | .0090 | .0050 | .0070 | .4571 | .0039 |

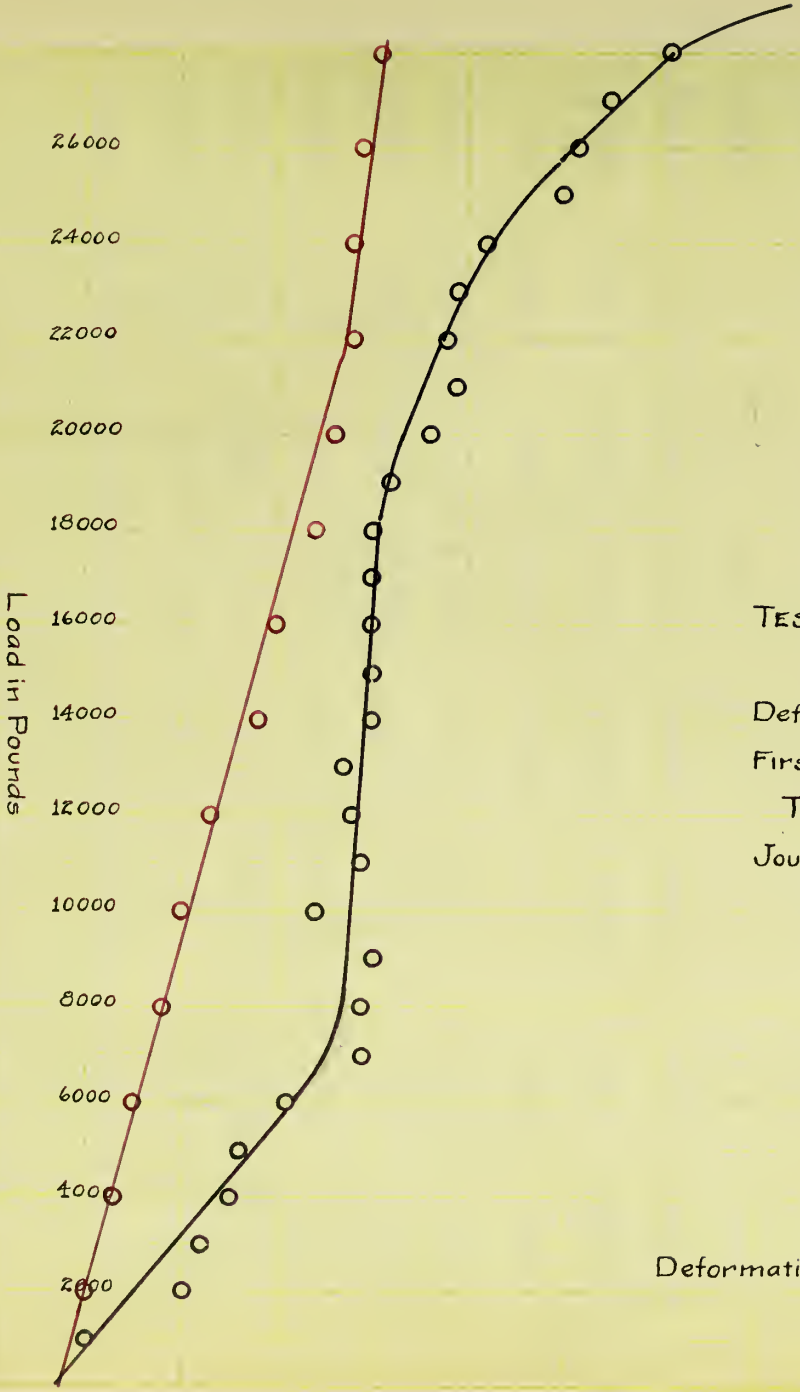
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 24000 | .0756 | .0409 | .0096 | .0052 | .0074 | .4568 | .0042 |
| 25000 | .0771 | .0413 | .0111 | .0056 | .00835 | .4560 | .0050 |
| 26000 | .0792 | .0416 | .0132 | .0059 | .00955 | .4559 | .0051 |
| 27000 | .0838 | .0404 | .0178 | .0047 | .01125 | .4535 | .0055 |
| 28000 | .0872 | .0394 | .0212 | .0037 | .01245 | .4549 | .0061 |
| 29000 | .0986 | .0397 | .0326 | .0020 | .01730 | .4534 | .0076 |

CHECK on TEST #5 SAMPLE #3

# STUD LINK CHAIN

| Load | Readings | | Difference | Aver. | | Read | Diff. |
|---|---|---|---|---|---|---|---|
| 1000 | .0266 | .0909 | — | — | — | .5549 | — |
| 2000 | .0263 | .0911 | -.0003 | .0002 | -.00005 | .5549 | .0000 |
| 4000 | .0268 | .0923 | .0002 | .0014 | .0008 | .5546 | .0003 |
| 6000 | .0270 | .0932 | .0004 | .0023 | .00135 | .5544 | .0005 |
| 8000 | .0276 | .0937 | .0010 | .0028 | .00190 | .5541 | .0008 |
| 10000 | .0276 | .0949 | .0010 | .0040 | .00250 | .5539 | .0010 |
| 12000 | .0279 | .0955 | .0013 | .0046 | .00295 | .5536 | .0013 |
| 14000 | .0279 | .0966 | .0013 | .0057 | .0035 | .5531 | .0018 |
| 16000 | .0283 | .0972 | .0017 | .0063 | .0040 | .5529 | .0020 |
| 18000 | .0283 | .0976 | .0017 | .0067 | .0042 | .5525 | .0024 |
| 20000 | .0285 | .0988 | .0019 | .0079 | .0049 | .5523 | .0026 |
| 22000 | .0289 | .0994 | .0023 | .0085 | .0054 | .5521 | .0028 |
| 24000 | .0291 | .1003 | .0025 | .0094 | .00595 | .5521 | .0028 |
| 26000 | .0289 | .1023 | .0023 | .0114 | .00685 | .5520 | .0029 |
| 28000 | .0283 | .1038 | .0017 | .0129 | .0073 | .5518 | .0031 |
| 30000 | .0282 | .1074 | .0016 | .0165 | .00905 | .5512 | .0038 |


26000
24000
22000
2000
18000
16000
14000
12000
10000
8000
6000
4000
2000
Load in Pounds
TEST 5 SAMPLE 3
STUD LINK
Deformations of Major Axis
First Test
Check Test
Theoretical Deformations
Journal Contact — Line Contact —
Deformations Scale ½" = .001"




TEST 5 SAMPLE 3

STUD LINK

Deformations of Minor Axis

First Test o Check Test o

Theoretical Deformations

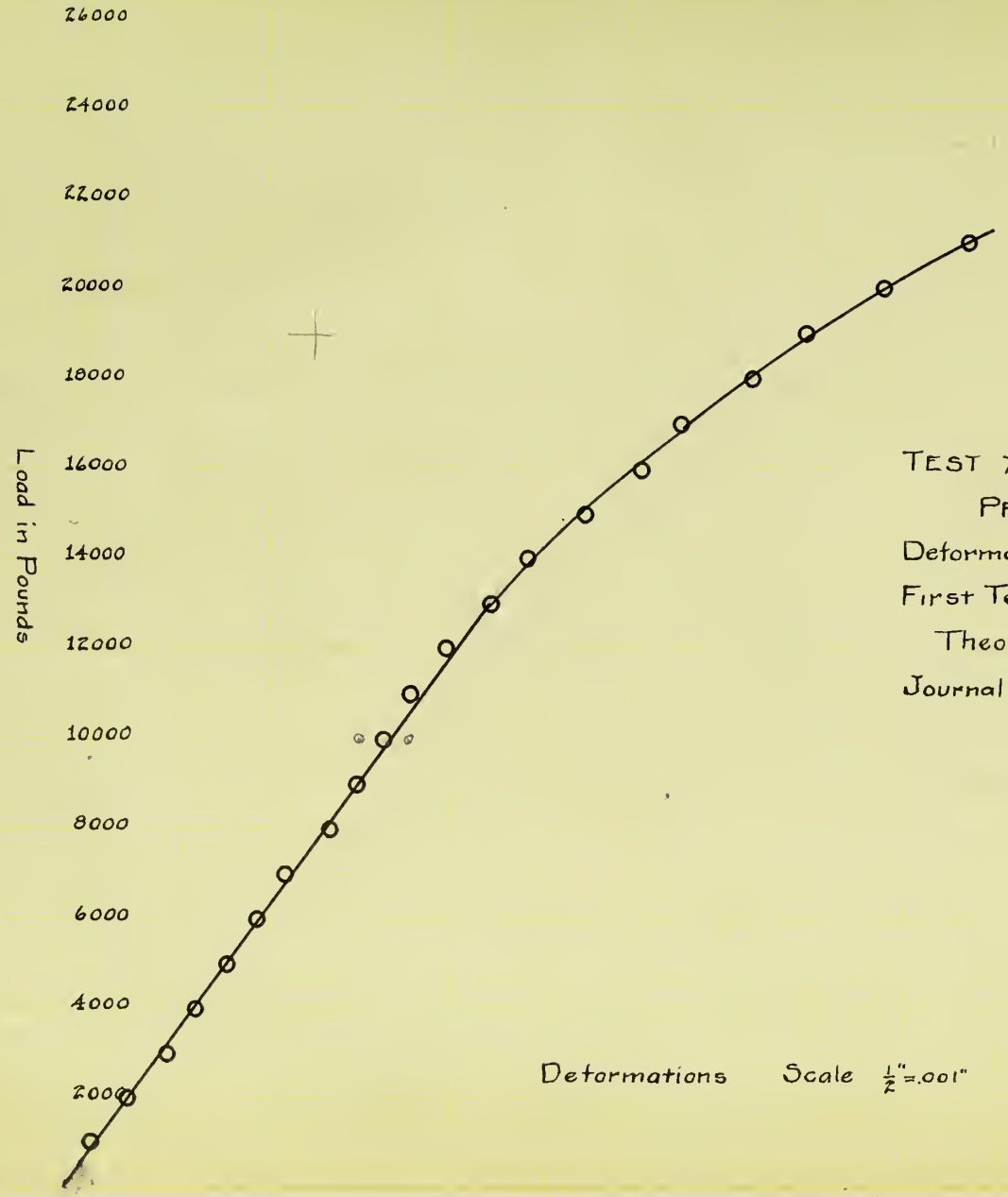
Journal Contact — Line Contact —

Deformations Scale $\frac{1}{2}$"=.001"

TEST #7 SAMPLE #4

# PROOF COIL CHAIN

| Load | Readings | | Difference | | Aver | Read. | Diff. |
|---|---|---|---|---|---|---|---|
| 1000 | .2006 | .2002 | — | — | — | .3872 | — |
| 2000 | .2010 | .2006 | .0004 | .0004 | .0004 | .3870 | .0002 |
| 3000 | .2017 | .2008 | .0011 | .0006 | .00085 | .3864 | .0008 |
| 4000 | .2021 | .2010 | .0015 | .0008 | .00115 | .3860 | .0012 |
| 5000 | .2022 | .2016 | .0016 | .0014 | .0015 | .3854 | .0018 |
| 6000 | .2026 | .2019 | .0020 | .0017 | .00185 | .3851 | .0021 |
| 7000 | .2030 | .2021 | .0024 | .0019 | .00215 | .3843 | .0029 |
| 8000 | .2034 | .2027 | .0028 | .0025 | .00265 | .3841 | .0031 |
| 9000 | .2038 | .2029 | .0032 | .0027 | .00295 | .3838 | .0034 |
| 10000 | .2041 | .2032 | .0035 | .0030 | .00325 | .3835 | .0037 |
| 11000 | .2045 | .2034 | .0039 | .0032 | .00355 | .3831 | .0041 |
| 12000 | .2049 | .2038 | .0043 | .0036 | .00395 | .3827 | .0045 |
| 13000 | .2054 | .2043 | .0048 | .0041 | .00445 | .3822 | .0050 |
| 14000 | .2060 | .2047 | .0052 | .0045 | .00485 | .3816 | .0056 |
| 15000 | .2066 | .2052 | .0060 | .0050 | .0055 | .3811 | .0061 |
| 16000 | .2071 | .2059 | .0065 | .0057 | .0061 | .3804 | .0068 |
| 17000 | .2078 | .2061 | .0072 | .0059 | .00655 | .3799 | .0073 |
| 18000 | .2087 | .2068 | .0081 | .0066 | .00735 | .3793 | .0079 |
| 19000 | .2097 | .2070 | .0091 | .0068 | .00795 | .3786 | .0086 |
| 20000 | .2108 | .2076 | .0102 | .0074 | .0088 | .3777 | .0095 |
| 21000 | .2119 | .2088 | .0113 | .0086 | .00975 | .3763 | .0109 |




TEST 7 SAMPLE 4

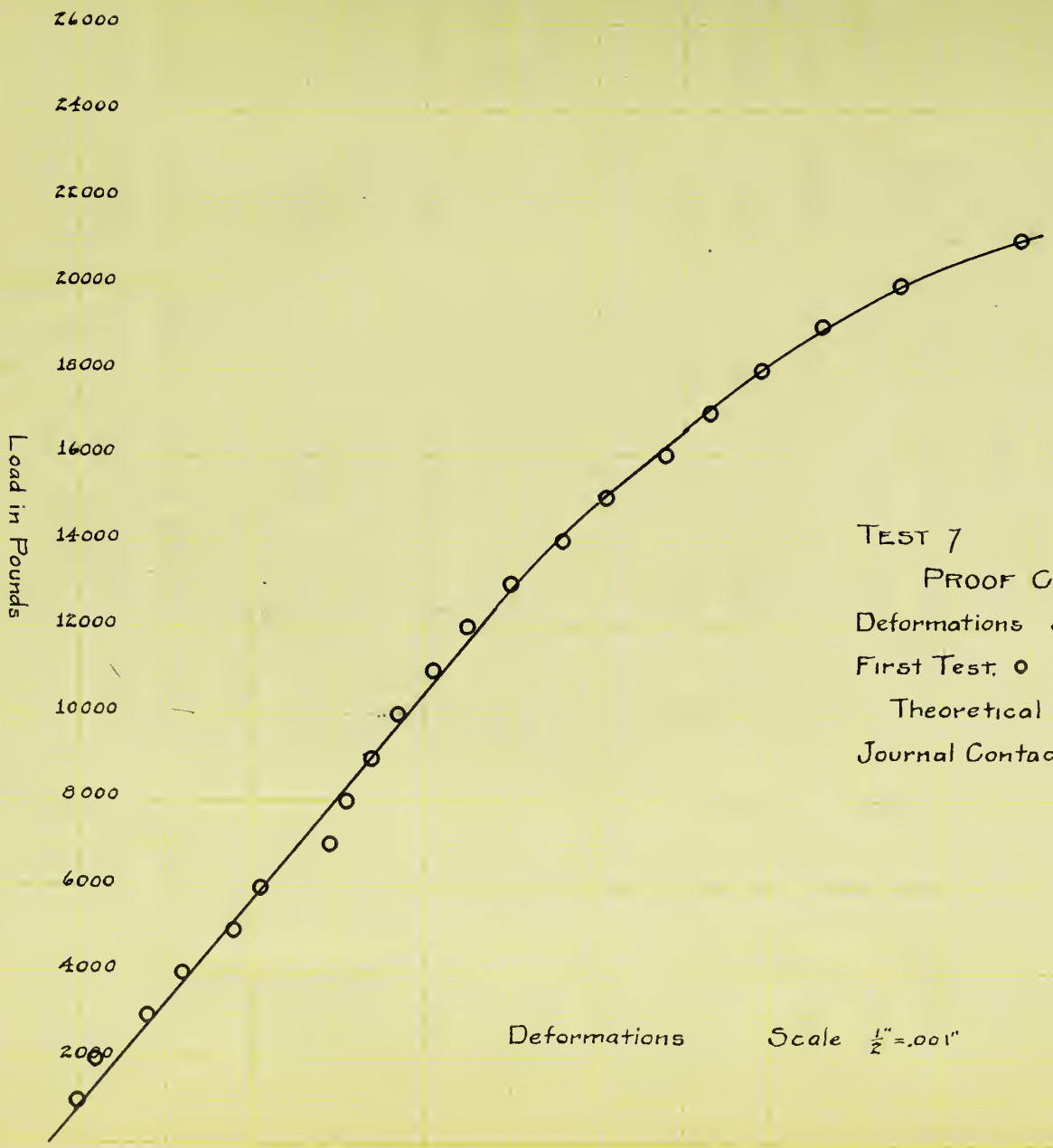
PROOF COIL CHAIN

Deformations of Major Axis

First Test o

Theoretical Deformations

Journal Contact — Line Contact




TEST 7 SAMPLE 4

PROOF COIL CHAIN

Deformations of Minor Axis

First Test. o

Theoretical Deformations

Journal Contact — Line Contact

TEST #6 SAMPLE #5

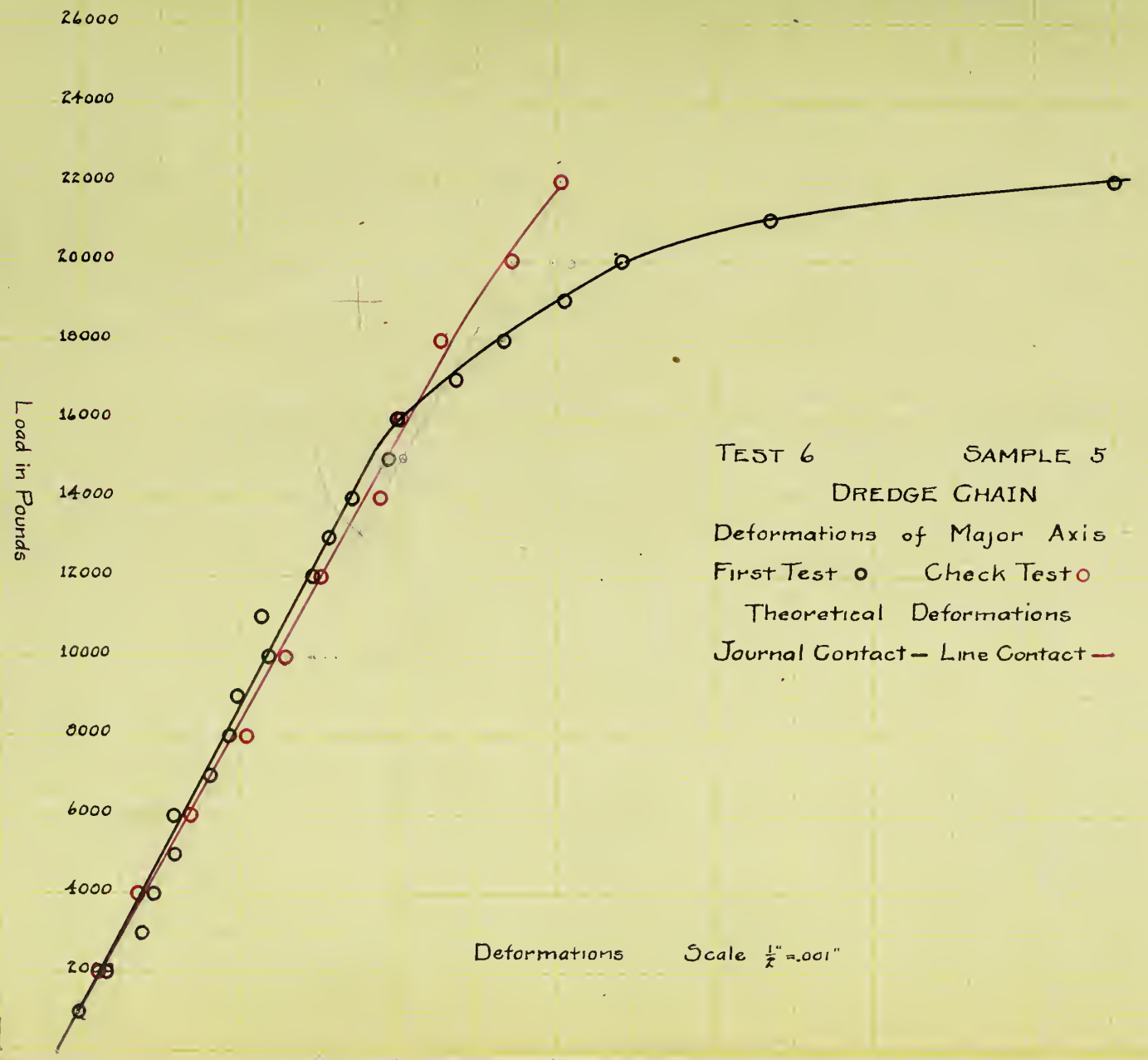
# DREDGE CHAIN

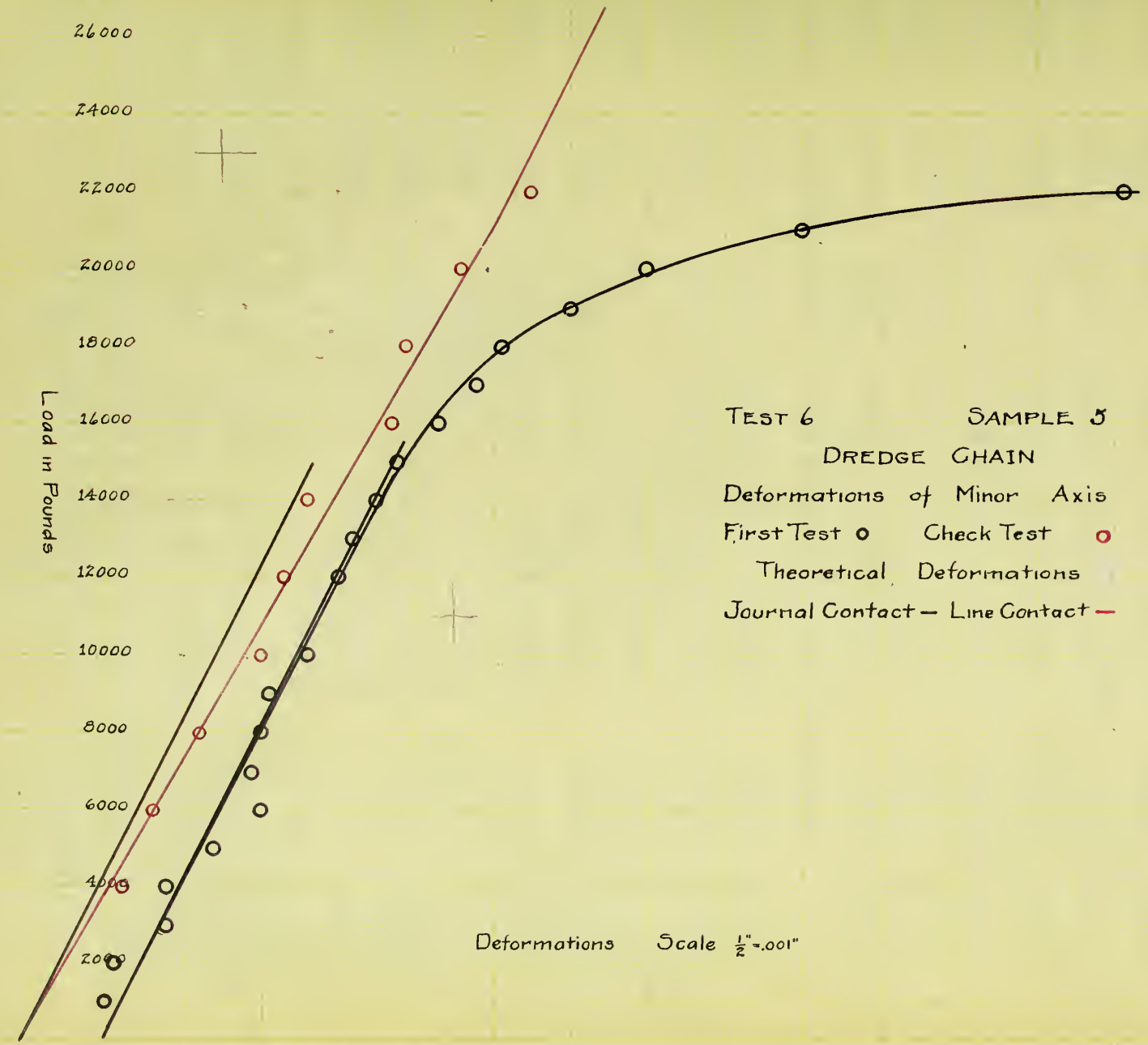
| Load | Readings | | Difference | | Aver. | Read. | Diff. |
|---|---|---|---|---|---|---|---|
| 10 00 | .0098 | .0125 | — | — | — | .5100 | — |
| 2000 | .0101 | .0129 | .0003 | .0004 | .00035 | .5099 | .0001 |
| 3000 | .0103 | .0136 | .0005 | .0011 | .0008 | .5092 | .0008 |
| 4000 | .0106 | .0136 | .0008 | .0011 | .00095 | .5092 | .0008 |
| 5000 | .0109 | .0138 | .0011 | .0013 | .0012 | .5086 | .0014 |
| 6000 | .0109 | .0138 | .0011 | .0013 | .0012 | .5080 | .0020 |
| 7000 | .0116 | .0140 | .0018 | .0015 | .00165 | .5081 | .0019 |
| 8000 | .0112 | .0149 | .0014 | .0024 | .0019 | .5080 | .0020 |
| 9000 | .0117 | .0146 | .0019 | .0021 | .0020 | .5079 | .0021 |
| 10000 | .0119 | .0152 | .0021 | .0027 | .0024 | .5074 | .0026 |
| 11000 | .0121 | .0149 | .0023 | .0021 | .0023 | — | — |
| 12000 | .0124 | .0158 | .0026 | .0033 | .00295 | .5070 | .0030 |
| 13000 | .0126 | .0160 | .0028 | .0035 | .00315 | .5068 | .0032 |
| 14000 | .0129 | .0163 | .0031 | .0038 | .00345 | .5065 | .0035 |
| 15000 | .0131 | .0170 | .0033 | .0045 | .0039 | .5062 | .0038 |
| 16000 | .0132 | .0171 | .0034 | .0046 | .0040 | .5057 | .0043 |
| 17000 | .0138 | .0180 | .0040 | .0055 | .00475 | .5052 | .0048 |
| 18000 | .0142 | .0188 | .0044 | .0063 | .00535 | .5049 | .0051 |
| 19000 | .0153 | .0192 | .0055 | .0067 | .0061 | .5040 | .0060 |
| 20000 | .0161 | .0199 | .0063 | .0074 | .00685 | .5030 | .0070 |
| 21000 | .0176 | .0221 | .0078 | .0096 | .0087 | .5010 | .0090 |
| 22000 | .0216 | .0267 | .0118 | .0142 | .0130 | .4969 | .0131 |

CHECK on TEST #6 SAMPLE #5

# DREDGE CHAIN

| Load | Readings | | Difference | | Aver. | Read. | Diff. |
|---|---|---|---|---|---|---|---|
| 1000 | .0033 | .0035 | — | — | — | .2036 | — |
| 2000 | .0035 | .0038 | .0002 | .0003 | .00025 | .2035 | .0001 |
| 4000 | .0038 | .0045 | .0005 | .0010 | .00075 | .2034 | .0002 |
| 6000 | .0042 | .0054 | .0009 | .0019 | .0014 | .2030 | .0006 |
| 8000 | .0048 | .0062 | .0015 | .0027 | .0021 | .2024 | .0012 |
| 10000 | .0048 | .0072 | .0015 | .0037 | .0026 | .2016 | .0020 |
| 12000 | .0051 | .0078 | .0018 | .0043 | .00305 | .2013 | .0023 |
| 14000 | .0059 | .0085 | .0026 | .0050 | .0038 | .2010 | .0026 |
| 16000 | .0061 | .0088 | .0028 | .0053 | .00405 | .1999 | .0037 |
| 18000 | .0058 | .0101 | .0025 | .0066 | .00455 | .1997 | .0039 |
| 20000 | .0068 | .0111 | .0033 | .0076 | .00545 | .1990 | .0046 |
| 22000 | .0069 | .0120 | .0036 | .0085 | .00605 | .1981 | .0055 |
| 24000 | .0326 | .0248 | .0293 | .0213 | .0253 | .—— | —— |


26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
Load in Pounds
TEST 6 SAMPLE 5
DREDGE CHAIN
Deformations of Major Axis
First Test o Check Test o
Theoretical Deformations
Journal Contact — Line Contact —
Deformations Scale 1/2" = .001"


26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
Load in Pounds
TEST 6 SAMPLE 5
DREDGE CHAIN
Deformations of Minor Axis
First Test o Check Test o
Theoretical Deformations
Journal Contact — Line Contact —
Deformations Scale ½"=.001"

TEST #9 SAMPLE #6

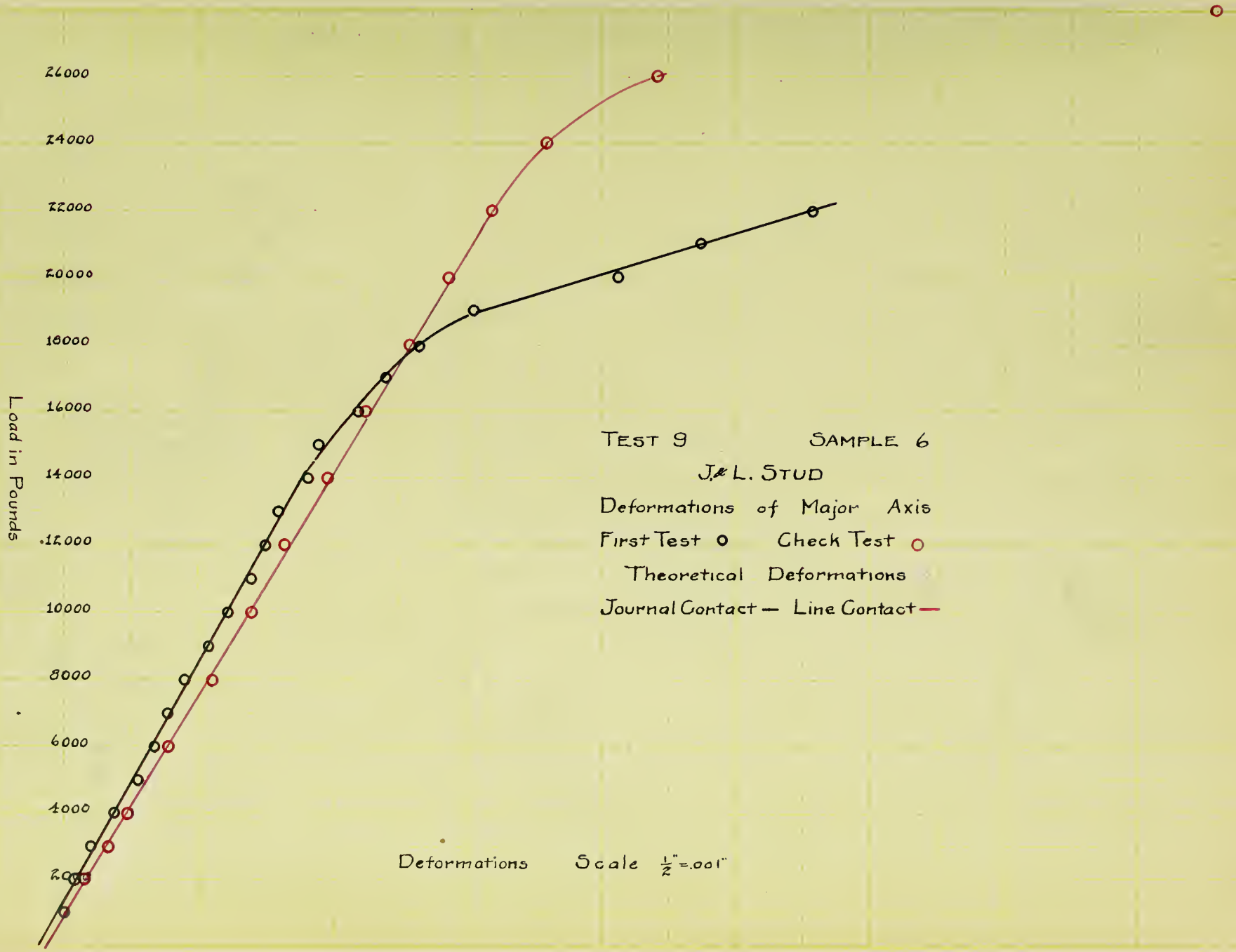
# J. & L. STUD LINK.

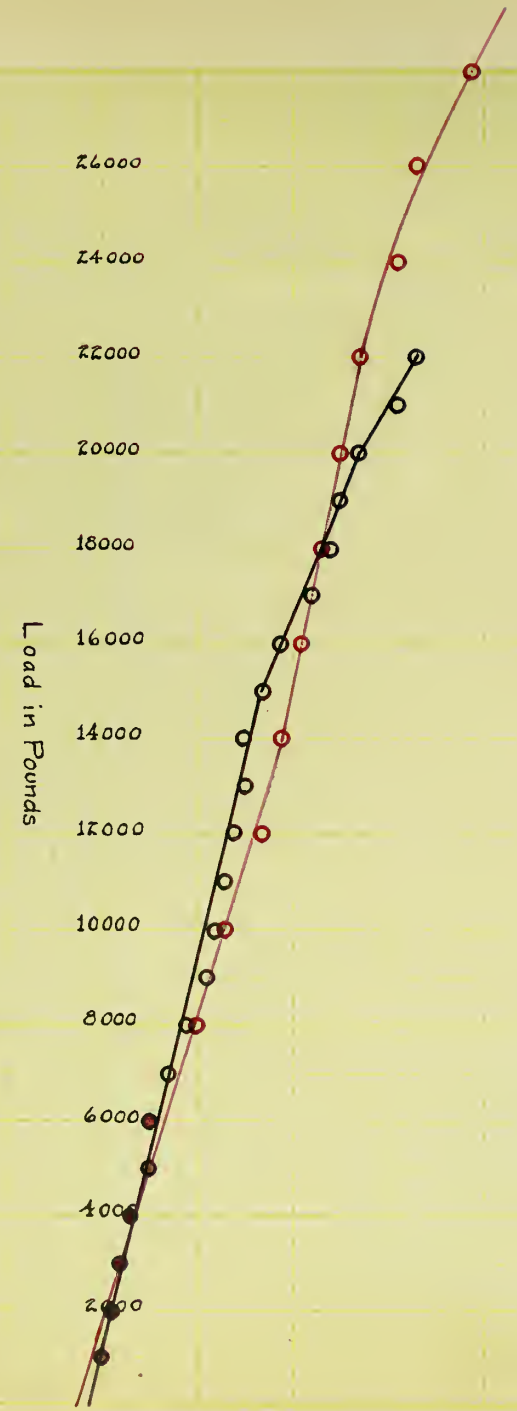
| Load | Readings | | Difference | | Aver. | Read. Diff. | |
|---|---|---|---|---|---|---|---|
| 1000 | .0042 | .0027 | — | — | — | .2045 | — |
| 2000 | .0044 | .0028 | .0002 | .0001 | .00015 | .2044 | .0001 |
| 3000 | .0047 | .0030 | .0005 | .0003 | .0004 | .2043 | .0002 |
| 4000 | .0051 | .0033 | .0009 | .0006 | .00075 | .2042 | .0003 |
| 5000 | .0055 | .0036 | .0013 | .0009 | .0011 | .2040 | .0005 |
| 6000 | .0058 | .0038 | .0016 | .0011 | .00135 | .2040 | .0005 |
| 7000 | .0060 | .0040 | .0018 | .0013 | .00155 | .2038 | .0007 |
| 8000 | .0064 | .0041 | .0022 | .0014 | .0018 | .2036 | .0009 |
| 9000 | .0068 | .0044 | .0026 | .0017 | .00215 | .2034 | .0011 |
| 10000 | .0071 | .0047 | .0029 | .0020 | .00245 | .2033 | .0012 |
| 11000 | .0076 | .0049 | .0034 | .0022 | .0028 | .2032 | .0013 |
| 12000 | .0079 | .0050 | .0037 | .0023 | .0030 | .2031 | .0014 |
| 13000 | .0080 | .0053 | .0038 | .0026 | .0032 | .2030 | .0015 |
| 14000 | .0086 | .0056 | .0044 | .0029 | .00365 | .2030 | .0015 |
| 15000 | .0089 | .0058 | .0047 | .0031 | .0038 | .2028 | .0017 |
| 16000 | .0094 | .0063 | .0052 | .0036 | .0044 | .2026 | .0019 |
| 17000 | .0097 | .0068 | .0055 | .0041 | .0048 | .2023 | .0022 |
| 18000 | .0102 | .0075 | .0060 | .0046 | .0053 | .2021 | .0024 |
| 19000 | .0107 | .0084 | .0065 | .0057 | .0061 | .2020 | .0025 |
| 20000 | .0120 | .0114 | .0078 | .0087 | .00825 | .2018 | .0027 |
| 21000 | .0126 | .01331 | .0084 | .0106 | .0095 | .2014 | .0031 |
| 22000 | .0118 | .0174 | .0076 | .0147 | .01115 | .2012 | .0033 |

CHECK on TEST #9 SAMPLE #6

# J. & L. STUD LINK

| Load | Readings | | Differences | | Aver. | Read. | Diff. |
|---|---|---|---|---|---|---|---|
| 1000 | .0058 | .0084 | —— | —— | —— | .2825 | —— |
| 2000 | .0059 | .0089 | .0001 | .0005 | .0003 | .2854 | .0001 |
| 3000 | .0062 | .0093 | .0004 | .0009 | .00065 | .2823 | .0002 |
| 4000 | .0064 | .0097 | .0006 | .0013 | .00095 | .2822 | .0003 |
| 6000 | .0070 | .0103 | .0012 | .0019 | .00155 | .2820 | .0005 |
| 8000 | .0077 | .0109 | .0019 | .0025 | .0022 | .2815 | .001 |
| 10000 | .0082 | .0116 | .0024 | .0032 | .0028 | .2812 | .0013 |
| 12000 | .0087 | .0121 | .0029 | .0037 | .0033 | .2808 | .0017 |
| 14000 | .0091 | .0130 | .0033 | .0046 | .00395 | .2806 | .0019 |
| 16000 | .0097 | .0135 | .0039 | .0051 | .0045 | .2804 | .0021 |
| 18000 | .0101 | .0144 | .0043 | .0060 | .00515 | .2802 | .0023 |
| 20000 | .0106 | .0151 | .0048 | .0067 | .00575 | .2800 | .0025 |
| 22000 | .0110 | .0160 | .0052 | .0076 | .0064 | .2798 | .0027 |
| 24000 | .0117 | .0169 | .0059 | .0085 | .0072 | .2794 | .0031 |
| 26000 | .0114 | .0205 | .0056 | .0121 | .00885 | .2792 | .0033 |
| 28000 | .0136 | .0300 | .0078 | .0216 | .0172 | .2786 | .0039 |


26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
Load in Pounds
TEST 9 SAMPLE 6
J. & L. STUD
Deformations of Major Axis
First Test o Check Test o
Theoretical Deformations
Journal Contact — Line Contact —
Deformations Scale 1/2" = .001"




TEST 9 SAMPLE 6

J. & L. STUD

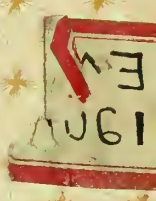
Deformations of Minor Axis

First Test o Check Test o

Theoretical Deformations

Journal Contact — Line Contact —

Deformations Scale $\frac{1}{2}$" = .001"



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